JPRS 82684

20 January 1983

EAST EUROPE REPORT

POLITICAL, SOCIOLOGICAL AND MILITARY AFFAIRS

No. 2097

NUCLEAR WEAPONS AND PROTECTION AGAINST NUCLEAR WEAPONS

East Berlin KERNWAFFEN UND KERNWAFFENSCHUTZ in German Aug 72 pp 1-500

[Book by Lt Col Docent Manfred Hoffmann, Dr. Mil. Sci.; textbook with 85 tables and 175 illustrations; Military Publishing House of the German Democratic Republic]

CONTENTS

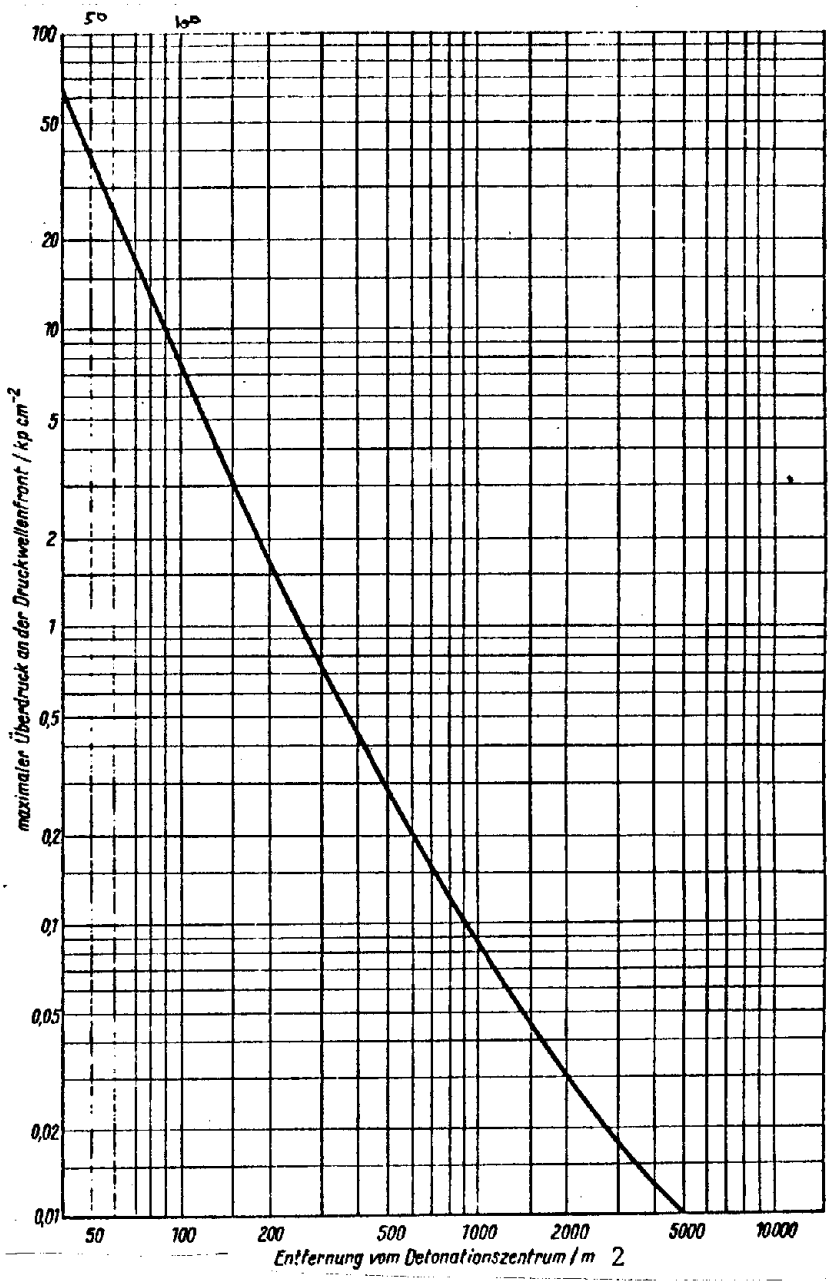


Figure 3.8. Maximum overpressure along air blast wave front as function of distance deriving from 1-kt ground burst.[4] Key: 1--Maximum overpressure along blast wave front, kt cm^{-2}; 2--Distance from detonation center, m.

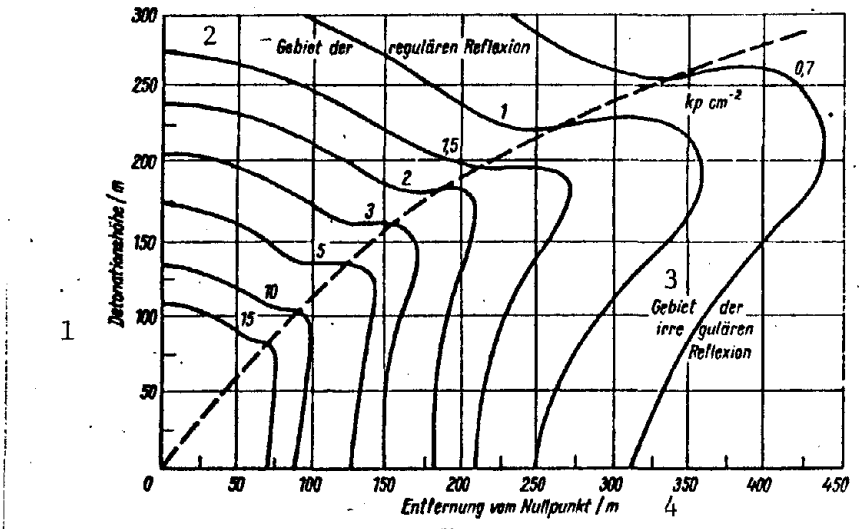


Figure 3.9. Maximum overpressure along air blast wave front as function of distance from ground zero and detonation altitude after 1-kt air burst (range of overpressure Δp_f from 0.7 kp cm^{-2} to 15 kp cm^{-2}). Key: 1--Detonation altitude, m; 2--Region of regular reflection; 3--Region of irregular reflection; 4--Distance from ground zero, m.

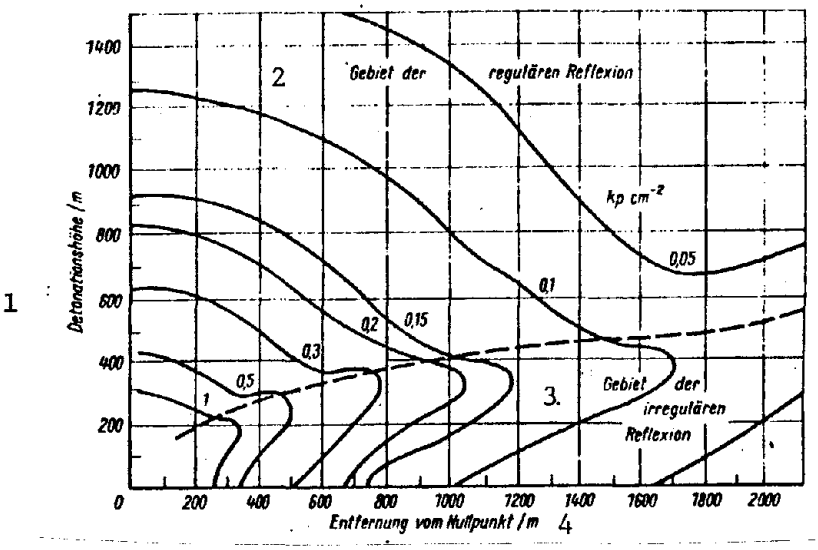


Figure 3.10. Maximum overpressure along air blast wave front as function of distance from ground zero and detonation altitude after 1-kt air burst (range of overpressure Δp_f from 0.05 kp cm^{-2} to 1.0 kp cm^{-2}). Key: 1--Detonation altitude, m; 2--Region of regular reflection; 3--Region of irregular reflection; 4--Distance from ground zero, m.

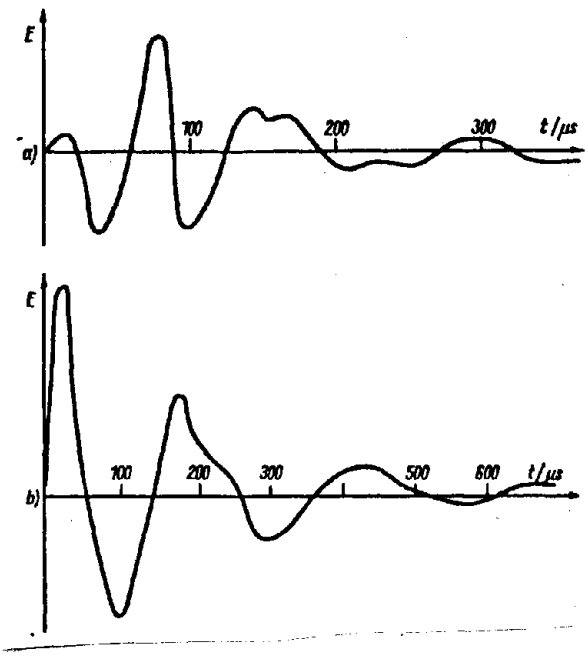


Figure 6.1. Comparison of "signals" produced by a nuclear weapon detonation and an atmospheric discharge.[1] a--"Signal" of nuclear weapon detonation recorded at a distance of 3,000 km from the detonation center; b--"Signal" of a bolt of lightning received at a distance of 1,000 km.

In all nuclear weapon detonation, one source of the electromagnetic impulse is the heavy ionization of the air by the gamma component of instantaneous nuclear radiation. In case of high-altitude detonations, another source is the reciprocal effect of the highly ionized plasma of the detonation products with the earth's magnetic field.

The heavy ionization of the air in the case of nuclear weapon detonations does not remain confined only to the immediate fireball but, in case of detonations in the dense layers of the atmosphere, additionally covers a region with a thickness of several hundred meters around the fireball.

The gamma quantums, spreading to all sides from the detonation center, enter into a reciprocal action with the atoms and molecules in the air and transmit a large part of their energy to them. Here, the Compton effect predominates by far.

The energy-rich Compton electrons likewise move away from the detonation center at high speed. As a result of this there is a first current impulse and a relative shift or division of the negative and positive charges because the ionized atoms and molecules in fact remain on the spot. A radical electrical field is built up.

If the propagation of the electrons were to be based on complete spherical symmetry, then the external overall effect of the electromagnetic field would be equal to zero because the effect of each charged oscillating particle would again be cancelled out by the effect of the symmetrical particle which is opposite to it. This kind of symmetry however does not exist for various reasons.

The asymmetry in the propagation of the Compton electrons and thus also in the shape of the electromagnetic field results from the particular structure of the nuclear charge, the screening effect of the earth's surface, and the uneven air density in the individual directions. This is why the asymmetrical distribution of the electrons works as a short-time, directed charge impulse which, similar to an electrical dipole, radiates high-frequency energy which makes up the first part of the electromagnetic impulse of a nuclear weapon detonation.

The fast Compton electrons on their way lead to a secondary ionization; that is to say, we again get free electrons although with less energy. These free electrons begin to move toward the detonation center under the influence of the electrical primary field. They bring about a second current [flow] impulse and the buildup of a second electromagnetic field opposite to the first one. This process supplies the second part of the electromagnetic impulse of a nuclear weapon detonation. Its action time is shorter than that of the first part because the slower secondary electrons are recombined faster. These processes are repeated several times until a complete charge equalization has been achieved.

(There is no simple neutralization of the electromagnetic fields; this, in a simplified explanation, is due to the fact that many electrons are deposited along electrically neutral atoms and molecules as a result of which the process of complete recombination is delayed.)

Summarizing, we can say:

At the moment of a nuclear weapon detonation, pulsating electromagnetic fields and electrical currents are formed in the atmosphere and in the ground [earth] which, during their existence, emit electromagnetic waves of varying frequency.

Because of their short action time--it is something between microseconds and milliseconds--we speak of the electromagnetic impulse of a nuclear weapon detonation.

Its destructive effects are determined by the maximum field intensity (amplitude), the magnitude of the change in the field intensity with the passage of time, and the spectral composition of the emitted electromagnetic waves.

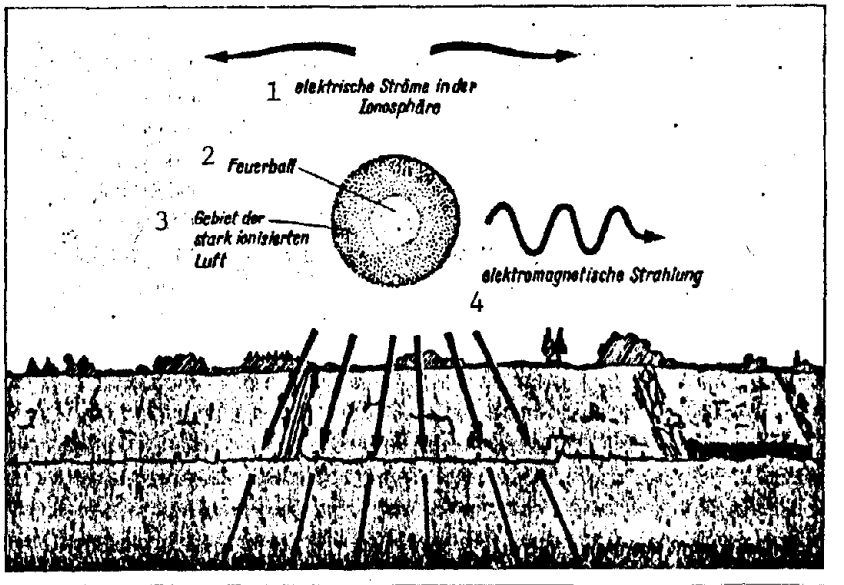


Figure 6.2. Origin of electromagnetic fields and electrical currents [fluxes] after nuclear weapon detonation.[3] Key: 1--Electrical currents in the ionosphere; 2--Fireball; 3--Region of heavily ionized air; 4--Electromagnetic radiation.

The electromagnetic impulse reveals a very broad frequency spectrum. According to data by Langhans[4], the ascent time of the primary impulse is about 10^{-8} so that the maximum frequencies will be around 100 Mhz. Electromagnetic waves with this kind of high frequency however are quickly absorbed as they are propagated in the atmosphere. This is why most of the energy share is concentrated in the low-frequency range of about 10-30 kHz.

The intensity and action time of the electromagnetic impulse rise relatively slowly with increasing detonation intensity.

The type of detonation essentially influences the duration of the impulse. In the case of ground and air bursts, the duration of the impulse is on the order of magnitude of several hundred microseconds up to several milliseconds; in the case of high-altitude bursts, it can take effect for several hundreds of milliseconds.

Review Questions

6.1. What are the fundamental properties of the electromagnetic impulse from a nuclear weapon detonation?

6.2. Can one draw initial conclusions from the observation that the electromagnetic impulse resembles atmospheric discharges--conclusions as to its basic effect and the required protective measures?

6.3. Why, in explaining the causes of the origin of the electromagnetic impulse, do we place such great value on the understanding of the significance of the assymmetrical charge distribution?

6.2. Propagation of Electromagnetic Impulse as a Function of Detonation Conditions

Depending on the detonation conditions, the electromagnetic impulse can spread over great distances. Here it is first of all suitable as a phenomenon in proving the existence of detonations; besides, the great field intensity values at shorter distances also will cause certain damage to electrical systems.

After ground bursts and low-altitude air bursts, the electromagnetic field is polarized vertically. Due to its effect there is an induction of electrical currents--which are directed radially from ground zero--not only in the air but also on the ground.

According to data by Flambard, the area of ground zero was marked with a metal carpet in connection with a French nuclear weapon test. This carpet was connected with a remote ground [earth plate] by means of a strong conductor. Under these conditions, a current peak value of 150,000 amperes was measured.[5]

According to available literature data, the annihilating or damaging effect of the electromagnetic impulse after detonations near the ground is confined to distances of several kilometers but can exceed the corresponding radii of the effect of the blast wave and light radiation. In this range, the field intensity amplitudes in the air can reach several tens of thousands of volt m^{-1} and in the earth they can reach 100-1,000 v m^{-1}. As the distance from ground zero increases, the amplitude values drop quickly.

Figure 6.3. shows some field intensity values as a function of the detonation intensity and the distance from the detonation center.[6]

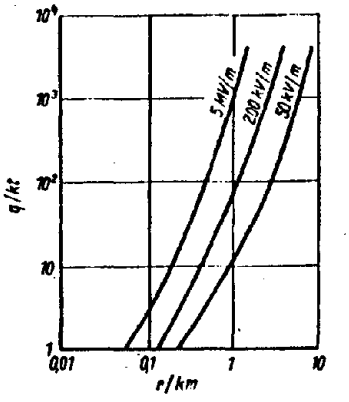


Figure 6.3. Reference values for field intensities of the electromagnetic impulse appearing after nuclear weapon detonations.

After air bursts we basically get the same phenomena as after ground bursts but the level of the field intensity amplitude drops quickly as the detonation altitude grows. Likewise, the currents produced in the ground are diminished due to the severe attenuation.

After underground and underwater detonations, there is practically no need to consider the propagation of the electromagnetic impulse in relation to the overall effects of the other annihilation factors.

Entirely different conditions for the propagation of the electromagnetic impulse result from high-altitude detonations outside the dense atmosphere. Here the electromagnetic impulse consists of two pronounced phases whereby especially the reciprocal effect of the ionizing plasma of the detonation products with the earth's magnetic field contributes to a powerful impulse during the second phase.

This is due to the fact that the free electrons, formed during ionization, in case of low air density, have long and free path distances (100-1,000 m) and perform spiral movements due to the action of the earth's magnetic field along the force lines. Here, a part of their kinetic energy is reflected [radiated away] in the form of electromagnetic waves (braking radiation).[7] According to various data, we are still supposed to be able to get maximum field intensity values on the order of magnitude of 100 kV m^{-1} after high-altitude detonations even at distances of several hundreds of kilometers from the detonation centers.

Review Questions

6.4. Explain the influence of detonation conditions on the propagation of the electromagnetic impulse of a nuclear weapon detonation.

6.5. What conclusions result from the fact that the electromagnetic impulse can induce powerful currents and fields also in the earth?

6.3. Annihilating Effects of Electromagnetic Impulse and Protection against Them

The electromagnetic impulse from a nuclear weapon detonation can damage radio, telephone, television, radar, as well as EDP equipment and systems, it can temporarily put out of action electric power plants and power supply systems, and it can also injure the people who operate them.

The damaging effects of the electromagnetic impulse are primarily based on the fact that it induces high voltages in all conductors with large linear dimensions with respect to the earth and these high voltages in turn can trigger short-time, sudden current surges.

This is why the electromagnetic impulse has a strong effect especially on overhead lines, underground cables, telephone lines, signal lines, etc. in that--due to the high overvoltages, as a function of the impulse resistance of the cables, lines, and equipment--the insulations are punctured, fuses and conductors are melted, semiconductor components are destroyed, and magnetic working materials are rendered useless.

Furthermore, we must anticipate the start of fires in electronic instruments. This shows that the electromagnetic impulse can greatly influence the system of wire communications. On the other hand, its direct effect on radio communications is far less. It is expressed only for fractions of seconds in the form of an interference impulse, similar to atmospheric disturbances, and can furthermore cause relatively low input voltages in radio sets. In

this connection we must not fail to mention the possible influence of the electromagnetic impulse on the operation of data processing systems.

The probability of the appearance of induction currents depends extensively on the shape of the electromagnetic impulse, that is to say, on the time change in the field intensity. On the other hand, the magnitude of induced voltages and thus also of the currents is determined by the maximum field intensity appearing at the particular distance from the detonation center.

One must furthermore keep in mind that not the entire spectrum contributes equally to the induction of voltages and currents. Instead, frequencies of several kHz are decisive here primarily.

It is especially this part of the overall spectrum which becomes weaker particularly quickly upon the propagation of electromagnetic waves in the air and in the ground. This is why the annihilating effect of the electromagnetic impulse remains confined to several kilometers after ground and air bursts.

The magnitude of the voltage induced in a conductor is a complex function of the detonation intensity, the length of the conductor or the amplifier field, the distance from the detonation center, the direction of the conductor in relation to ground zero, the detonation altitude, and other factors. This is why generalizable statements are difficult to make. We might therefore present some numerical data taken from Jastak here.[8] Accordingly, overvoltages of several hundreds of thousands of volts can appear between overhead lines. The overvoltages between a ground cable and the ground themselves are several hundred times greater than between the individual cable strands. Telecommunications systems are exposed to the heaviest stresses. The maximum stressability for DC is assumed to be 4 kv.

For the electromagnetic impulse on the other hand we generally get an impulse strength of 10 kv and in case of a lightning rod system we have a figure of as much as 50 kv.

Most resistant are high-voltage lines with impulse strengths of several hundred kilovolts (see Figure 6.3). But nuclear weapon detonations at high altitudes, because of the extremely high field intensity values, can, at these altitudes likewise, induce voltages of several hundred kilovolts up to distances of 100 km and more from the detonation center and thus damage them.

Weather conditions greatly influence the impulse strength [resistance]. In case of rain or wet weather, this resistance can drop for instance by as much as one order of magnitude.

From the problems we have taken up so far we can clearly see that, among others, much attention must be devoted to the protection of communications equipment against the damaging effects of the electromagnetic impulse from nuclear weapon detonations for the sake of providing steady communications.

In a simplified manner one might assume that this involves questions similar to protection against lightning. In reality, the implementation of protection against the electromagnetic impulse turns out to be much more complicated because we are dealing here not only with the protection of transmission systems but also with all of the pertinent lines, in other words, the entire system as a whole.

The most important protective measures for lines and cables include the following:

Basic laying of symmetrical two-conductor systems which are well insulated against the ground;

Underground cables which consist of several conductors of identical electrical capacity must be laid in metal pipes to reduce possible overvoltages between the cable and the ground to a minimum?

Attainment of short amplifier field lengths, that is to say, limitation of voltage and current peaks, due to the installation of protective systems (current and voltage fuses) which will quickly be regenerated automatically in order to achieve short interrupter times;

Good grounding of shieldings.

The following requirements must be added for the protection of instruments and systems:

Installation of special protective circuits;

Continuous grounding of instruments;

Lining of cabins and workrooms, in which electronic and electrical instruments are installed, with rubber mats or other insulating materials;

Carrying out fire protection requirements.

For special protection for human beings it is necessary to avoid contact with metal parts, for example, the housings of communications equipment. Under certain circumstances one may also have to wear protective gloves.

Summarizing we can say here that the most important requirements for protection against the annihilating effects of the electromagnetic impulse from a nuclear weapon detonation must be considered and implemented during the design and construction of the particular equipment and systems.

Review Questions

6.6. What are the physical processes to which one can trace the annihilating or damaging effects of the electric magnetic impulse?

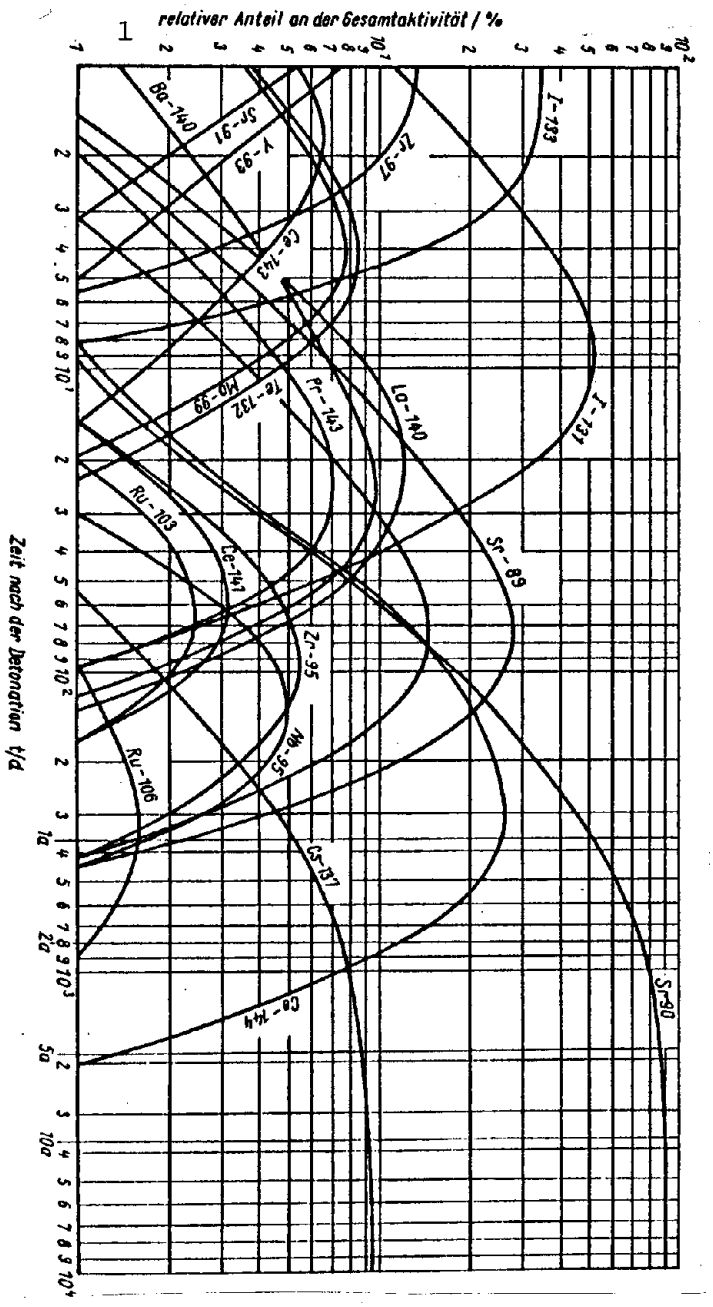


Figure 7.3. Change in relative share of fission products of some important radionuclides as a function of the time.[6] Key: 1--Relative share out of total radioactivity, %; 2--Time after detonation, t, d.

Table 7.3. Characteristic Data on Important Radionuclides of the Fission Product Mixture from a Nuclear Weapon Detonation

	1 Radionuklid	Symbol	2 Strahlungs-typ	3 Halbwert-zeit	4 $E_{\beta(max)}$ / MeV	4 $E_{\beta(mittel)}$ / MeV
	Krypton-85	$^{85}_{36}Kr$	β^-, γ	9,4 a	0,7	0,22
	Strontium-89	$^{89}_{38}Sr$	β^-	53 d	1,5	0,57
	Strontium-90	$^{90}_{38}Sr$	β^-	19,9 a	0,5	0,20
	Zirkonium-95	$^{95}_{40}Zr$	β^-, γ	66 d	0,9	0,17
10	Molybdän-99	$^{99}_{42}Mo$	β^-, γ	67 h	1,2	1,1
	Ruthenium-103	$^{03}_{44}Ru$	β^-, γ	42 d	0,25	0,07
	Ruthenium-106	$^{106}_{44}Ru$	β^-	1,0 a	0,04	0,01
	Jod-131	$^{131}_{53}J$	β^-, γ	8 d	0,6	0,21
	Xenon-133	$^{133}_{54}X$	β^-, γ	5,3 d	0,3	0,01
11	Cäsium-137	$^{137}_{55}Cs$	β^-, γ	33 a	0,6	0,18
12	Barium-140	$^{140}_{56}Ba$	β^-, γ	12,8 d	0,8	0,27
	Cer-141	$^{141}_{58}Ce$	β^-, γ	30 d	0,5	0,15
13	Neodym-147	$^{147}_{60}Nd$	β^-, γ	11 d	0,7	0,26

[Continued on following page]

Table 7.3. [Continued from preceding page]

E_γ / MeV 5	Anteil der Gammaquanten je Zerfallsprozeß/%	6 Angaben zum Verhalten bei Inkorporation: 7 kritische Organe	8 biologische Halbwertzeit	9 effektive Halbwertzeit
0,54	0,65	–	–	–
–	–	14 Knochen	49 a	51 d
		15 Gesamtkörper	35 a	50,3 d
–	–	14 Knochen	49 a	18 a
		15 Gesamtkörper	35 a	16 a
0,72	99	14 Knochen	3 a	61 d
0,23	1	16 Nieren, Milz	2,5 a	60 d
		15 Gesamtkörper	1,2 a	56 d
0,18	97,5			
0,78	2,5	14 Knochen	150 d	2,8 d
0,74	17,5			
		17 Muskeln	12 d	9 d
0,50	96	16 Nieren, Leber	16 d	12 d
		14 Knochen	0,5 a	30 d
		15 Gesamtkörper	16 d	12 d
–	–	17 Muskeln	12 d	11,5 d
		16 Nieren, Leber	16 d	15 d
		14 Knochen	0,5 a	0,4 a
		15 Gesamtkörper	16 d	15 d
0,37	81	18 Schilddrüse	140 d	8 d
		15 Gesamtkörper	138 d	7,6 d
0,08	36	–	–	–
		17 Muskeln	140 d	138 d
0,66	92	19 Leber	90 d	89 d
		14 Knochen	140 d	138 d
		15 Gesamtkörper	70 d	40 d
0,54	30	14 Knochen	65 d	11 d
0,03	100			
0,16	70	15 Gesamtkörper	65 d	11 d
		14 Knochen	4 a	31 d
0,15	67	19 Leber	0,8 a	29 d
		20 Nieren	1,6 a	30 d
		15 Gesamtkörper	1,6 a	30 d
0,09	60	14 Knochen	4 a	11 d
0,32	15	19 Leber	130 d	10 d
0,53	25	20 Nieren	1,8 a	11 d
		15 Gesamtkörper	1,8 a	11 d

Key: 1--Radionuclides; 2--Radiation type; 3--Half-life; 4--Average; 5--Share of gamma quantums per decay process, %; 6--Data on response in case of incorporation; 7--Critical organs; 8--Biological half-life; 9--Effective half-life; 10--Molybdenum-99; 11--Cesium-137; 12--Barium-140; 13--Neodymium-147; 14--Bones; 15--Whole body; 16--Kidneys, spleen;17--Muscles; 18--Pancreas; 19--Liver; 20--Kidneys.

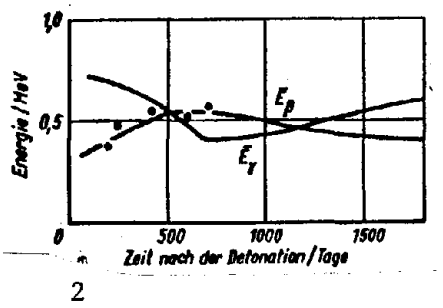


Figure 7.4. Change in average energy of beta and gamma radiation of fission products during time interval of up to 1,500 days following detonation.[12] Key: 1--Energy, Mev; 2--Time after detonation, days.

The dose rate and the cumulative energy of gamma radiation of fission products are directly proportional to each other but their ratio changes with the passage of time.

If we furthermore assume proportionality between the change of the cumulative radioactivity of the fission products and the cumulative dose rate (see Table 7.4), then it follows, in analogy to Formula 7.1, that we have, for the decline in the dose rate with the passage of time after detonation:

$$P(t) = P_0 \left(\frac{t}{t_0}\right)^n \qquad (7.2)$$

whereby however for the exponent we find applicable the value n = -1.2 with adequate accuracy only for a period of time of up to 10 days following the detonation.

Because times t > 10 days play a subordinate role for investigations under field conditions, we might make reference at this point only to the data in Table 7.5.[11]

For resolving a series of practical questions of unit protection against the annihilating effects of residual nuclear radiation in conjunction with operations in radioactively contaminated areas (nuclear radiation monitoring, dosimetry, estimating protected properties offered by combat vehicles and facilities) it is necessary to know the change in the energy of gamma and beta radiation from fission products during the passage of time after nuclear weapon detonations.

The graph in Figure 7.4 presents a rough overview.

Figure 7.5 shows additional values, broken in detail for the time interval of up to 10 days after detonation. Here it must however be kept in mind that the average maximum energy of beta radiation has been plotted.

Table 7.4. Cumulative Radioactivity of Fission Products (U-235) and Cumulative Energy of Gamma Radiation as a Function of the Time

1	Zeit nach der Kernwaffendetonation			
	1 h	7 h	1 d	2 d
$\Sigma A/Z$ s^{-1} kt^{-1}	$1{,}5 \cdot 10^{19}$	$1{,}7 \cdot 10^{18}$	$4{,}4 \cdot 10^{17}$	$1{,}7 \cdot 10^{17}$
$\Sigma E\gamma$ /MeV s^{-1} kt^{-1}	$9{,}0 \cdot 10^{18}$	$8{,}0 \cdot 10^{17}$	$2{,}0 \cdot 10^{17}$	$9{,}1 \cdot 10^{16}$
ΣA:$\Sigma E\gamma$	1,7	2,1	2,2	1,9
	4 d	7 d	10 d	20 d
$\Sigma A/Z$ s^{-1} kt^{-1}	$7{,}3 \cdot 10^{16}$	$4{,}0 \cdot 10^{16}$	$2{,}9 \cdot 10^{16}$	$1{,}5 \cdot 10^{16}$
$\Sigma E\gamma$ /MeV s^{-1} kt^{-1}	$3{,}6 \cdot 10^{16}$	$2{,}2 \cdot 10^{16}$	$1{,}5 \cdot 10^{16}$	$7{,}3 \cdot 10^{15}$
ΣA:$\Sigma E\gamma$	2,0	1,8	1,9	2,1
	30 d	100 d		
$\Sigma A/Z$ s^{-1} kt^{-1}	$9{,}2 \cdot 10^{15}$	$2{,}4 \cdot 10^{15}$		
$\Sigma E\gamma$ /MeV s^{-1} kt^{-1}	$4{,}4 \cdot 10^{15}$	$7{,}9 \cdot 10^{14}$		
ΣA:$\Sigma E\gamma$	2,1	3,0		

Key: 1--Time after nuclear weapon detonation; h--hr.

Table 7.5. Average Values of the Exponent n to Calculate the Fading of the Dose Rate of Fission Products as a Function of the Time after Detonation

1 Zeit nach der Detonation	n
1 min $< t <$ 30 min	−0,89
30 min $\leqq t <$ 1 d	−1,11
1 d $\leqq t <$ 4 d	−1,25
4 d $\leqq t <$ 3 a	−1,60
3 a $\leqq t <$ 20 a	−0,35
20 a $\leqq t <$ 50 a	−1,0
50 a $\leqq t <$ 100 a	−2,0

Key: 1--Time after detonation.

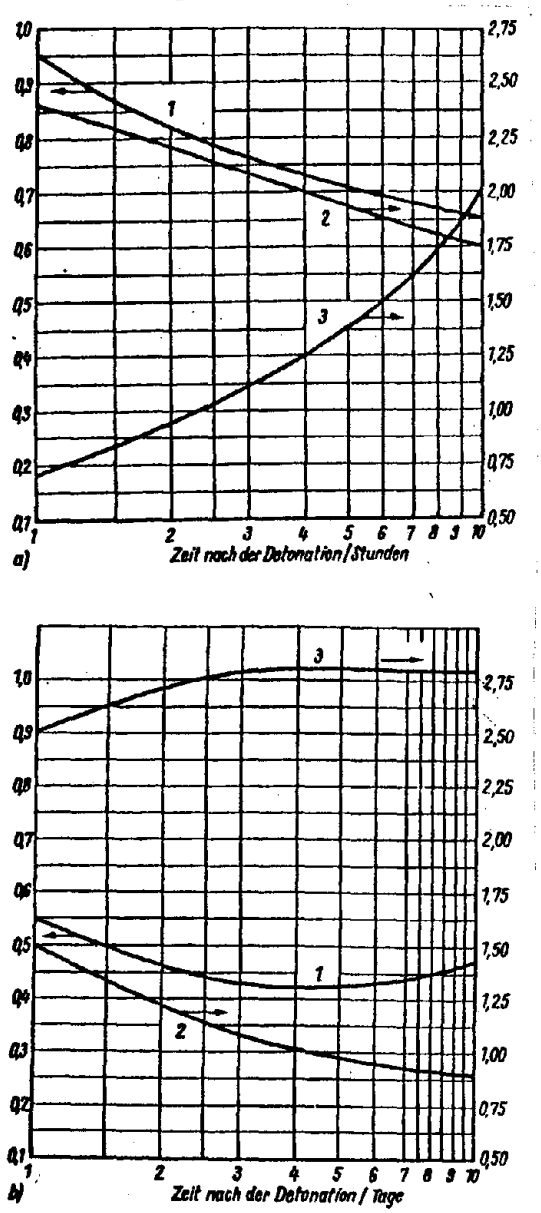


Figure 7.5. Change in average maximum energy of beta radiation and average energy of gamma radiation as well as average dose constant of gamma radiation of fission products for the first 10 days after detonation[+].
a--1-10 hours after detonation; b--1-10 days after detonation
[+]1--Average energy of gamma radiation, MeV; 2--Average maximum energy of beta radiation, MeV; 3--Dose constant of gamma radiation of fission products, R cm^2 h^{-1} mCi^{-1}.
(To get the dose constant in the customary unit of R m^2 h^{-1} Ci^{-1}, the values in the table must be multiplied with the factor 10^{-1}. The unit of measure mentioned results from the double use of the scale subdivision.)
Key: 1--Time after detonation, hours; 2--Time after detonation, days.

Figure 7.5 shows that one can figure on an average gamma radiation energy value of 0.7 MeV during a period of 1-10 hours following the detonation. For a subsequent interval of up to 10 days, an average value of 0.5 MeV indicates the gamma radiation energy with adequate accuracy.[13] The average maximum energy of beta radiation from fission products between 1 and 10 hours after the detonation is 2 MeV (average energy 0.7 MeV) and between 1 and 10 days it is 1.2 MeV (average energy 0.35 MeV).

For radiation calculations under field conditions, especially for problems of radiation protection in shelters, Spencer points out that it turns out to be best to use the gamma radiation spectrum of the fission products 1 hour

after the detonation as basis. This view is justified by saying that, first of all, the essential share of the effective nuclear radiation dose comes from the first few hours after detonation and, besides, the spectrum of gamma radiation from fission products 1 hour after detonation characterizes the penetrating properties of gamma radiation rather well also for those of a different age.

This gamma spectrum is illustrated in Figure 7.6 also for a comparison of the spectrums 1 day and 10 days after detonation.[14]

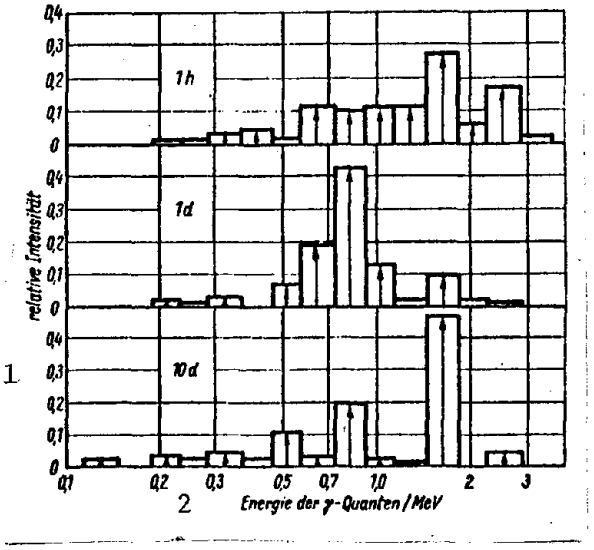


Figure 7.6. Relative intensity of spectral components of gamma radiation of fission product mixture at various times after detonation. (In the drawing, the height of each rectangle is in proportion of gamma radiation of that energy interval out of the total spectrum whereby the arrows drawn are the energy characteristics assumed for the calculation of the given interval. Gaseous fission products are not considered here). Key: 1--Relative intensity; 2--Energy of gamma quantums, MeV.

Along with the change in the composition of the fission product mixture during the passage of time after detonation there is also a change in the average ratio of the beta particles and gamma quantums emitted per decay process. This ratio--for fission products which originated during the fission of U-235 by means of thermal neutrons--is based on Bjoernerstedt and is indicated in Figure 7.7.[15]

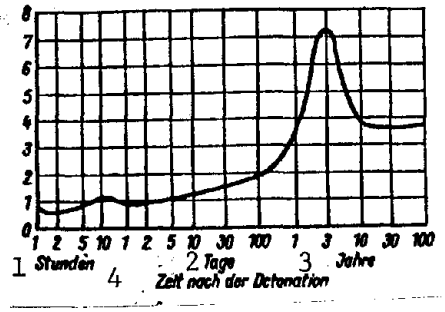


Figure 7.7. Average ratio of beta particles and gamma quantums, emitted per decay process, as function of the time after a nuclear weapon detonation. Key: 1--Hours; 2--Days; 3--Years; 4--Time after detonation.

We may assume that similar ratios result from the fission of other nuclear explosives due to fast neutrons.

The illustration shows that, up to 5 days following the detonation, the ratio between the beta particles and the gamma quantums emitted per decay process is below or at 1, whereas after 100 days it has a value of 2, keeps growing and 3 years after the detonation reaches a maximum of about 7. This means, in other words, that during this period of time, the relative share of gamma radiation out of the cumulative energy declines constantly as the age of the fission products increases.

7.1.2. Neutron-Induced Radioactivity

While the quantity and properties of radioactive fission products developing after nuclear weapon detonations can be estimated with adequate accuracy, this is not readily the case regarding neutron-induced radioactivity, briefly also called induced radioactivity.

This is above all due to the fact that, in addition to the influence of the design and makeup of the particular nuclear weapon, and here again especially the type of energy release, the type of nuclear weapon detonation and the nature of the detonation area also have an extraordinarily strong effect. This results not only in certain difficulties in the evaluation of the scope of anticipated induced radioactivity, for example, the estimate of radioactive terrain contamination in the area of a low-altitude air burst, but also in the interpretation and further processing of corresponding measurement values.

Regardless of that we can say that both concerning the overall radioactivity induced after nuclear weapon detonations, and the size of the surface areas which are thus radioactively contaminated, we get considerable differences compared to radioactive contamination from fission products. As the data in Table 7.1 already clearly indicated, the values of neutron-induced radioactivity are by several orders of magnitude below those of the fission products even in case of underground detonations. On top of that we have the fact that--apart from the directly induced radioactivity in the nuclear weapon's construction materials--the production of radioactive nuclides due to neutron radiation in point of fact is always confined to the immediate area around ground zero.

Neutron-induced radioactivity originates due to the interaction of the fission or synthesis neutrons, released as a result of nuclear weapon detonations, with the structural elements of the weapon, the nonreacting part of the nuclear charge, as well as various elements of the surrounding medium. The character of these reciprocal processes depends heavily on the energy of the neutrons. It is above all the stable atomic nuclei which are converted into radioactive nuclides due to neutron capture.

In Section 5.2.6 we already pointed out that, in the case of nuclear fission or three-phase nuclear weapons, we get an average of one free neutron per 120 MeV of released total energy so that we get about $2.25 \cdot 10^{23}$ neutrons for a detonation intensity of 1 kt.

The reciprocal processes between these neutrons and the surrounding medium specifically depend on:

The density and the energy spectrum of the neutrons at the particular point in space and

The concentration and action cross-sections[16] if the nuclei able to be radioactivized by the elements of the surrounding medium.

Low-energy neutrons were captured with greater probability than those of higher energy. The nuclei forming due to neutron capture are in the excited state and can subsequently be subjected to beta decay which can be accompanied with the emission of gamma radiation.

For the majority of nuclei we find applicable $\sigma_1 (n, \gamma) \sim E^{-1/2}$ for the action cross-section of neutron capture with subsequent radioactive decay for low-energy neutrons and we find applicable $\sigma_1 (n, \gamma) \sim E^{-1}$ for high-energy neutrons.[17]

To estimate the orders of magnitude of neutron-induced radioactivity, Lavrenchik[18] starts with the assumption that high-energy neutrons are very quickly slowed down by elastic or inelastic processes of scatter (see Section 5.3.1.2), and he therefore performs the calculations on the basis of the capture of thermal neutrons in an infinite medium.

Under these assumptions, the number of developing nuclei of a certain radionuclide is directly proportional to the neutron flux F and the product from the concentration of the initial nuclei of this nuclide m_1 and their capture cross-section σ_1 and it is inversely proportional to the sum of the products from the concentrations of other nuclides m_μ and their capture cross-section σ_μ.

If we label the neutrons spent for the formation of a radionuclide with N_1, then the following applies:

$$N_1 = \frac{F \cdot m_1 \cdot \sigma_1}{\sum_{k=1}^{n} (m_\mu \cdot \sigma_\mu)_k} \qquad (7.3)$$

In addition to the processes of elastic and inelastic scatter and neutron capture with subsequent radioactive decay, however, we must expect further reciprocal processes after the use of multi-phase nuclear weapons.

For example, high-energy neutrons (superfast neutrons) with nuclei of light elements can lead to reactions of type (n, α) and (n, p).

In the structural elements used in the nuclear weapon and the unfissioned part of the nuclear charge, the reaction (n, 2n) under these conditions also plays a great role. For example, for neutrons with an energy of 14 MeV (see Section 5.1.3), the cross-section of radioactive capture averages no more than 1 percent of the cross-section of the reaction (n, 2n). Due to the

action of these neutrons, the corresponding nuclides U-232, U-234, U-235, and Pu-238 are formed from the nuclei of the nuclear charge U-233, U-235, U-238, and Pu-239. In a similar manner, the radionuclides Mn-54, Fe-53, Fe-55, W-181, and W-185 are formed in the construction elements. The significance of radioactive neutron capture then grows with the decline in the energy of the neutrons.

Because of the high neutron density, repeated capture reactions are possible in conjunction with nuclear fission and nuclear synthesis processes for the unfissioned part of the nuclear charge. For example, small quantitites of the nuclides Es-255 and Fm-255 were proved and their formation requires 17 successive capture reactions.

The radionuclides, induced by the neutron component of instantaneous nuclear radiation, other things being equal, depend on the type of detonation or, better still, on the elementary composition of the surrounding medium.

The air's induced radioactivity can essentially be traced back to the radionuclide Ar-41. The radionuclides Al-28, Mn-56, Na-24, Si-31, and Fe-59 are primarily responsible for the induced radioactivity of the ground. The induced radioactivity of sweet water is small and is based primarily on radionuclides Mn-56 and Na-24; the induced radioactivity of salt water on the other hand can be very high and is caused above all by the radionuclides Na-24, Cl-38, Br-80, and K-42.

Because the percentage share of these elements in the ground and in the other media is not constant, we get locally widely differing radioactivity conditions.

Table 7.7 shows the theoretical values of the possible activation sources for a three-phase nuclear weapon with a detonation intensity of 1 Mt ($2 \cdot 10^{26}$ free neutrons, including half of them with an energy of about 14 MeV).

Table 7.6. Characteristics of the Most Important Neutron-Induced Radionuclides in the Earth's Crust, Ocean Water, River Water, and the Air after a 20-kt Detonation ($6 \cdot 10^{24}$ Neutrons) according to Lavrenchick[19]

	Parameter	Elemente, die einen entscheidenden Beitrag zur summaren induzierten Aktivität leisten						
2	**Erdrinde**	Si	Fe	Ca	Na	K	P	Mn
3	Anteil/g cm^{-3}	0,74	0,13	0,10	0,075	0,07	0,003	0,002
4	Anzahl der Atome des Elements je Kubikzentimeter Boden	$1,5 \cdot 10^{22}$	$1,4 \cdot 10^{21}$	$1,5 \cdot 10^{21}$	$2 \cdot 10^{21}$	$1,1 \cdot 10^{21}$	$6 \cdot 10^{19}$	$2,2 \cdot 10^{19}$
5	induziertes Radionuklid	Si-31	Fe-59	Ca-45	Na-24	K-42	P-32	Mn-56
6	Einfangquerschnitt für thermische Neutronen/barn	0,4	2,5	0,63	0,51	1,2	0,19	13
7	Anzahl der aktivierten Kerne: $F \cdot m_i \cdot \sigma_i / \Sigma m_\mu \cdot \sigma_\mu$	$3,6 \cdot 10^{21}$	$3 \cdot 10^{20}$	$4 \cdot 10^{20}$	$2 \cdot 10^{22}$	$5,5 \cdot 10^{20}$	$2,2 \cdot 10^{20}$	$5,8 \cdot 10^{21}$
8	Aktivität 1 h nach der Detonation/Ci	$5,2 \cdot 10^{6}$	$1,3 \cdot 10^{3}$	540	$6,8 \cdot 10^{6}$	$1,4 \cdot 10^{5}$	$3,4 \cdot 10^{3}$	$1,4 \cdot 10^{7}$
9	Aktivität 1 d nach der Detonation/Ci	$1,4 \cdot 10^{4}$	$1,3 \cdot 10^{3}$	538	$2,2 \cdot 10^{6}$	$3,8 \cdot 10^{4}$	$3,2 \cdot 10^{3}$	$2,4 \cdot 10^{4}$
10	**Meerwasser**	Na	Cl	S	Mg	Ca	K	Br
11	Konzentration/g cm^{-3} $H_2O \cdot 10^{-3}$	10,5	19,2	0,9	1,3	0,4	0,4	0,3
12	Anzahl der Atome des Elements je Kubikzentimeter Wasser	$2,7 \cdot 10^{20}$	$3,3 \cdot 10^{20}$	$1,7 \cdot 10^{19}$	$3 \cdot 10^{19}$	$6 \cdot 10^{18}$	$6 \cdot 10^{18}$	$2,3 \cdot 10^{18}$
5	induziertes Radionuklid	Na-24	Cl-38	S-35	Mg-27	Ca-45	K-42	Br-80
6	Einfangquerschnitt für thermische Neutronen/barn	0,5	0,56	0,26	0,06	0,63	1,2	10,4
7	Anzahl der aktivierten Kerne: $F \cdot n_i \cdot \sigma_i / m \cdot \sigma^1)$	$3,7 \cdot 10^{22}$	$1,2 \cdot 10^{22}$	$4,7 \cdot 10^{19}$	$5,4 \cdot 10^{19}$	$2 \cdot 10^{19}$	$1,3 \cdot 10^{20}$	$3,8 \cdot 10^{21}$
8	Aktivität 1 h nach der Detonation/Ci	$1,2 \cdot 10^{7}$	$2,5 \cdot 10^{7}$	$1,1 \cdot 10^{2}$	$1,7 \cdot 10^{4}$	27	$5,3 \cdot 10^{4}$	$3,5 \cdot 10^{6}$
9	Aktivität 1 d nach der Detonation/Ci	$4 \cdot 10^{6}$	–	$1,1 \cdot 10^{2}$	–	27	$1,3 \cdot 10^{4}$	10^{5}

[Continued on following page]

Table 7.6. [Continued from preceding page]

	Parameter 1	Elemente, die einen entscheidenden Beitrag zur summaren induzierten Aktivität leisten		
13	**Flußwasser**	Cu	Mn	Na
11	**Konzentration/g cm^{-3} $H_2O \cdot 10^{-6}$**	0,02	0,3	6,0
12	**Anzahl der Atome des Elements je Kubikzentimeter Wasser**	$1{,}9 \cdot 10^{14}$	$3{,}3 \cdot 10^{15}$	$1{,}6 \cdot 10^{17}$
5	**induziertes Radionuklid**	Cu-64	Mn-56	Na-24
6	**Einfangquerschnitt für thermische Neutronen/barn**	4,3	13	0,5
7	**Anzahl der aktivierten Kerne:**			
	$F \cdot m_1 \cdot \sigma_1/m \cdot \sigma^1$)	$2{,}2 \cdot 10^{17}$	$1{,}2 \cdot 10^{19}$	$2{,}1 \cdot 10^{19}$
8	**Aktivität 1 h nach der Detonation/Ci**	120	$2{,}5 \cdot 10^4$	10^4
9	**Aktivität 1 d nach der Detonation/Ci**	37	160	3500
14	**Luft**	N	Ar	
15	**Anzahl der Atome des Elements je Kubikzentimeter Luft**	$4{,}3 \cdot 10^{19}$	$5{,}6 \cdot 10^{17}$	
5	**induziertes Radionuklid**	C-14	Ar-41	
6	**Einfangquerschnitt für thermische Neutronen/barn**	1,75	0,53	
7	**Anzahl der aktivierten Kerne:**			
	$F \cdot m_1 \cdot \sigma_1/\Sigma m_\mu \cdot \sigma_\mu$	$5{,}7 \cdot 10^{24}$	$2{,}4 \cdot 10^{22}$	
8	**Aktivität 1 h nach der Detonation/Ci**	620	$4 \cdot 10^7$	
9	**Aktivität 1 d nach der Detonation/Ci**	620	$4 \cdot 10^3$	

Key: 1--Elements making a decisive contribution to summary [cumulative] induced radioactivity; 2--Earth's crust; 3--Share, g/cm^{-3}; 4--Number of atoms of the element per cm^3 of ground; 5--Induced radionuclide; 6--Capture cross-section for thermal neutrons, barn; 7--Number of activated nuclei; 8--Radioactivity 1 hour after detonation, Ci; 9--Radioactivity 1 day after detonation, CI; 10--Ocean water; 11--Concentration; 12--Number of atoms of element per cm^3 water; 13--River water; 14--Air; 15--Number of atoms of element per cm^3 of air. (1) In these figures, m is the number of hydrogen nuclei per cm^3 and σ is the capture cross-section of hydrogen for thermal neutrons.

Table 7.7. Ratio between the Various Activation Sources after Detonation of 1-Mt Nuclear Weapon

1 Quelle der Aktivierung	2 Aktivität/Ci nach 1 Tag (3)	7 Tagen (4)	50 Tagen (5)
Spaltprodukte (6)			
($7{,}2 \cdot 10^{25}$ Spaltprozesse) (7)	$4 \cdot 10^9$	$4 \cdot 10^8$	$4 \cdot 10^7$
U-237 aus der Reaktion (n, 2n) (8)			
mit U-238 (10^{25} Neutronen)	$2 \cdot 10^8$	$1 \cdot 10^8$	$6 \cdot 10^5$
induzierte Nuklide: (9)			
in der Erdrinde (10)	10^8	$1{,}4 \cdot 10^6$	10^6
im Süßwasser (11)	10^5	$5 \cdot 10^2$	10^2
im Meerwasser (12)	10^7	$4 \cdot 10^5$	$2 \cdot 10^5$
in der Luft (13)	10^5	$2 \cdot 10^4$	$2 \cdot 10^4$

Key: 1--Source of radioactive contamination; 2--Radioactivity, Ci; 3--1 day; 4--7 days; 5--50 days; 6--Fission products; 7--Fission processes; 8--U-237 from the reaction (n, 2n) with U-239 (10^{25} neutrons); 9--Induced nuclides; 10--In earth's crust; 11--In sweet water; 12--In ocean water; 13--In air.

The calculations were made on the basis of an infinite medium and using the capture cross-section for thermal neutrons. The table shows that the essential share out of the total radioactivity comes from the fission products.[20]

To investigate radioactive contamination of the terrain under field conditions we are above all interested in the induced radioactivity of the ground in the area of ground zero after air bursts. Here, the total radioactivity as a rule is traced back to the radionuclides Al-28, Mn-56, and Na-24, while the other shares (see Table 7.6) are neglected.

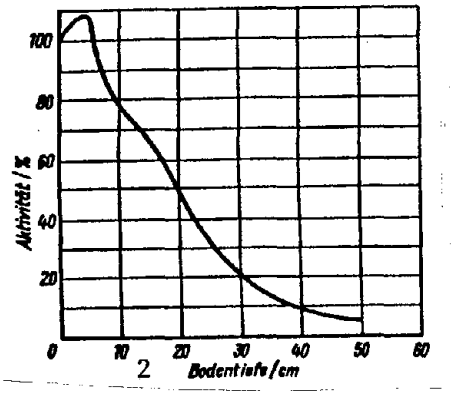
During the first few minutes after the detonation, the radionuclide Al-28 ($T_{1/2}$ = 2.3 min) contributes decisively to the cumulative dose rate of gamma radiation with 1.8 MeV per decay, whereas during the period of time of up to 1 week, the radionuclides Mn-56 (1.2 MeV/decay) and Na-24 (4.2 Mev/decay) supply the main shares. After that, the radionuclide Fe-59 (1.2 MeV/decay) assumes significance.

To be able to make specific statements as to the physical behavior of induced nuclides, it is necessary to start with a certain soil composition. Table 7.8 provides some reference values for this.

Table 7.8. Some Data on the Radionuclides Primarily Responsible for the Induced Radioactivity of the Ground[21]

Parameter	Element Al	Na	Mn
durchschnittliche Verbreitung/%			
in der Erdrinde	7,85	2,8	0,075
im Podsolboden	3,9	0,67	0,02
in kastanienfarbener Erde	6,7	0,9	0,28
in Schwarzerde	6,9	0,7	0,02
in Grauerde	6,8	1,7	–
Berechnungswert	7	1	0,06
Einfangquerschnitt für thermische Neutronen/barn	0,215	0,51	13
induziertes Radionuklid	Al-28	Na-24	Mn-56
Halbwertzeit	2,3 min	14,9 h	2,6 h

Key: 1--Average spread, %; 2--In the Earth's crust; 3--in Podsol ground; 4--In chestnut-colored earth; 5--In black earth; 6--In grey earth; 7--Calculation value; 8--Capture cross-section for thermal neutrons, barn; 9--Induced radionuclides; 10--Half-life.



1

2

Figure 7.8. Approximate percentage distribution of induced radioactivity as function of soil depth for low-altitude air bursts of nuclear fission weapons. Key: 1--Radioactivity, %; 2--Soil depth, cm.

The calculation of neutron-induced radioactivity in the detonation area of air bursts on the basis of the radionuclides Al-28, Mn-56, and Na-24 (using the calculation values given in Table 7.8 for the shares of the individual elements in mass-percent [weight-percent]) gives an average error of 30 percent for the equation[22]

$$\sum A_i(t) = F(1{,}87 \cdot 10^{-4} \cdot e^{-18t} + 7{,}15 \cdot 10^{-7} \cdot e^{-0{,}269t} + 2{,}06 \cdot 10^{-7} \cdot e^{-0{,}046t}) \quad \text{Z min}^{-1}\,\text{cm}^{-3} \tag{7.4}$$

From this it finally follows for the defined conditions that:

$$P(t) = P_0 \frac{810 \cdot e^{-18t} + 1{,}97 \cdot e^{-0{,}269t} + 2{,}08 \cdot e^{-0{,}046t}}{810 \cdot e^{-18t_0} + 1{,}97 \cdot e^{-0{,}269t_0} + 2{,}08 \cdot e^{-0{,}046t_0}} \quad \text{R h}^{-1} \tag{7.5}$$

F--flux of slow (thermal) neutrons, n cm^{-2}; t--time after detonation, hrs; P--dose rate of gamma radiation, R hr^{-1}.

While the radioactive fission products from a nuclear weapon detonation are deposited on the earth's surface, the induced radionuclides are formed up to a certain soil depth. For low-level air bursts involving nuclear fission weapons, the percentage radioactivity distribution as a function of the soil depth is illustrated in Figure 7.8.

We can see that a part of the neutrons must be slowed down to thermal speeds only in the upper soil layer to be captured. From this we can conclude that the radioactivity maximum will be shifted to an even greater soil depth following the detonation of three-phased nuclear weapons and nuclear synthesis weapons.

The graphic illustration furthermore shows that almost 50 percent of the induced nuclides are formed at a soil depth of more than 20 cm and that about 10 percent are formed below 40 cm. Under these conditions, in other words, radioactive decontamination by removing the upper soil layer would not be successful.

In case of ground and underground detonations (we cannot go into any greater detail here regarding water and underwater detonations), there is a more or less close mixing of the fission products and the induced nuclides. Estimates concerning the radioactivity performance of both components beyond the values given in Tables 7.6 and 7.7 are difficult and there are very few indications in the accessible literature on that score.

One must first of all keep in mind here that it is impossible to base such calculations simply on the given "average" soil composition. For example, the data published as part of the American Plowshare Program[23] concerning radioactive contamination are based on a soil share of 14.5 percent aluminum, 0.18 percent manganese, and 4.9 percent sodium. These values are considerably higher than those assumed for formulas 7.4 and 7.5. In addition we have the fact that the detonation depth and thus also the mechanism of crater ejection has a strong effect on the properties and the distribution pattern of summary [cumulative] radioactive detonation products.

A basic illustration of this problem complex can be found among others in Nifontov.[24]

Accordingly one may assume that, in case of detonations with a complete internal effect, all neutrons are already essentially absorbed by the rocks within a radius of 1 m; that is to say, they are slowed down to thermal speeds and they are then captured. This undoubtedly even in smaller detonation depths leads to a situation where the induced radionuclides and the fission products are closely mixed and are ejected with the evaporated or melted earth.

Because of the low climbing altitude of the detonation cloud after underground detonations, compared to air detonations, and because of the deposit of a

large part of the radioactive detonation products directly in the area of the crater or in its vicinity, in the direction in which the detonation cloud moves off, the radioactivity of the fission products here likewise predominates in spite of the absolutely higher values of induced radioactivity.

In the area of the crater, just one day after detonation, the induced radioactivity came to 20-25 percent of the radioactivity of the fission products and then dropped to 1 percent in the course of a week.

Summarizing we can say that it is permissible with a great degree of probability to use the $t^{-1.2}$ law of fission products in rough calculations of the decline in dose rates after underground detonations. But a critical interpretation of the measurement or computation results is necessary here. This applies particularly to forward-looking dose calculations. One must furthermore keep in mind that the influence of induced radioactivity can be reflected not only in the immediate detonation area but in the entire fallout region. This is why several successive control measurements are necessary. This problem complex will be covered in greater detail in Section 7.4.

The radionuclides induced by the neutron component of instantaneous nuclear radiation in the soil, in the water, and in the air, are beta-active and beta-gamma-active. Concerning the soil's induced radioactivity, we can say that the average maximum energy of the beta particles and the average energy of the gamma quantums in the time interval of interest here, after the detonation (up to a maximum of one week), will be above the corresponding values of the fission products.

The nuclear radiation emitted by the induced radionuclides therefore during the first 4 days after the detonation will not only fade more slowly than that of the fission products but it also has a considerably greater penetration capacity than the former.

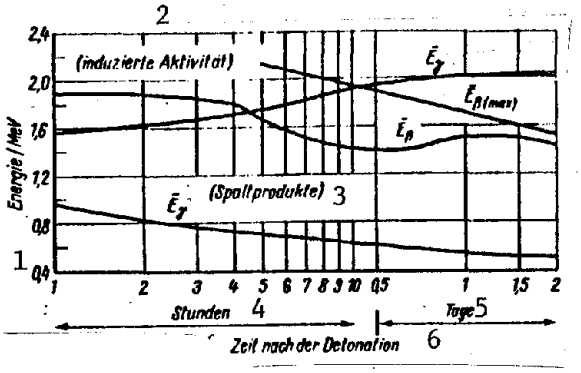


Figure 7.9. Change in energy of nuclear radiation, emitted by induced radionuclides in the ground, as a function of the time after the nuclear weapon detonation. Key: 1--Energy, MeV; 2--Induced radioactivity; 3--Fission products; 4--Hours; 5--Days; 6--Time after detonation.

Figure 7.9 illustrates some approximation values on the change of the average energy of gamma radiation and the average and average maximum energy of beta radiation of radionuclides induced in the soil over a period of time after nuclear weapon detonation.

Due to the effect of neutron radiation from a nuclear weapon detonation, we can also have the formation of induced radionuclides in various materials in combat equipment, ration items, etc. Generally valid statements on this problem complex are impossible and computations are rather complicated and time-consuming in detail. Besides, the accuracy attainable with simple aids leaves much to be desired. Nevertheless, such rough calculations may become necessary under certain conditions. The following formula can be used for this purpose.[25]

$$\sum A_i(t) = 0{,}017 \cdot F \sum_{1}^{n} 6 \cdot 10^{19} \cdot \varrho_i \cdot a_i \cdot b_i \cdot \frac{1}{M_i} \cdot \sigma_i \cdot \lambda_i \cdot e^{-\lambda \cdot t} \qquad (7.6)$$

$\sum A_i(t)$ --Specific induced summary [cumulative] beta activity at time t after detonation, Z min^{-1} cm^{-3}

F--Flux of slow (thermal) neutrons, n cm^{-2}

ρ_1--Density of i-th element, g cm^{-3}

σ_1--Share of i-th element in the substance to be investigated, mass-percent

b_1--share of radioactive isotope of the i-th element, %; if the element contains several essentially radioactive isotopes, the expression under the sum symbol for the i-th element must be separately calculated for each isotope and must be inserted as a partial sum into the total sum

M_1--Atomic mass of the i-th element, relative units

σ_i--Capture cross-section of considered isotope of i-the element, cm^{-3}

λ_1--Decay constant of considered radionuclide of i-the element, hr^{-1}

t--Time after detonation, hrs

n--Number of general elements designated with i which are to be included in the investigation.

In concluding the elementary considerations of neutron-induced radioactivity, Table 7.9 summarizes some characteristic data on important induced radionuclides.[26]

7.9. Characteristic Data on Important Induced Radionuclides Derived from Nuclear Weapon Detonation

1	Radionuklid	2 Symbol	3 Strahlungstyp	4 Halbwertzeit	$E_{\beta\,(max)}$ MeV	$E_{\beta\,(mittel)}$ MeV
10	Kohlenstoff-14	$^{14}_{6}C$	β^-	5568 a	0,16	0,05
11	Natrium-24	$^{24}_{11}Na$	β^-, γ	14,9 h	1,4	0,54
	Magnesium-27	$^{27}_{12}Mg$	β^-, γ	9,45 min	1,7	1,68
12	Silizium-31	$^{31}_{14}Si$	β^-, γ	2,6 h	1,47	–
13	Phosphor-32	$^{32}_{15}P$	β^-	14,5 d	1,7	0,69
14	Schwefel-35	$^{35}_{16}S$	β^-	87,1 d	0,17	0,06
15	Chlor-38	$^{38}_{17}Cl$	β^-, γ	37,7 min	4,8	1,39
	Argon-41	$^{41}_{18}Ar$	β^-, γ	1,8 h	1,2	0,4
16	Kalium-42	$^{42}_{19}K$	β^-, γ	12,5 h	3,6	1,4
	Calcium-45	$^{45}_{20}Ca$	β^-	153 d	0,26	0,08
17	Mangan-56	$^{56}_{25}Mn$	β^-, γ	2,6 h	2,86	0,89
18	Eisen-59	$^{59}_{26}Fe$	β^-, γ	45 d	1,56	0,12
19	Kupfer-64	$^{64}_{29}Cu$	β^-, β^+, γ	12,8 h	0,57 β^- 0,66 β^+	0,13

[Continued on following page]

Table 7.9. [Continued from preceding page]

E_γ / MeV	5 Anteil der Gammaquanten je Zerfallsprozeß/%	6 Angaben zum Verhalten bei Inkorporation: kritische Organe 7	biologische 8 Halbwertzeit	effektive 9 Halbwertzeit
–	–	20 Fett	12 d	12 d
		21 Knochen	40 d	40 d
2,75	100	22 Gesamtkörper	11 d	0,6 d
1,37	100			
1,02	30,1			
0,33	70	–	–	–
0,18	0,63			
1,26	0,07	–	–	–
–	–	21 Knochen	3,2 a	14,1 d
		23 Leber	18 d	8 d
		22 Gesamtkörper	257 d	13,5 d
–	–	21 Knochen	1,7 a	76 d
		22 Gesamtkörper	1,2 a	90 d
2,16	47	–	–	–
1,60	31			
1,29	99	–	–	–
1,51	18,2	Muskeln	58 d	0,5 d
0,32	0,2	22 Gesamtkörper	58 d	0,5 d
–	–	21 Knochen	49,4 a	152 d
		22 Gesamtkörper	45 a	152 d
2,9	0,2	23 Leber	25 d	0,1 d
2,6	0,1	24 Nieren	6,8 d	0,1 d
2,1	14,8	22 Gesamtkörper	17 d	0,11 d
1,8	24,9			
0,84	99,7			
1,29	43	23 Leber	1,5 a	41,7 d
1,10	56,7	21 Knochen	4,4 a	44 d
0,19	2,8	22 Gesamtkörper	2,2 a	43 d
1,34	0,43	22 Gesamtkörper	80 d	0,5 d
0,51	38			

Key: 1--Radionuclides; 2--Radiation type; 3--Half-life; 4--Average; 5--Share of gamma quantums per decay process, %; 6--Data for response in case of incorporation; 7--Critical organs; 8--Biological half-life; 9--Effective half-life; 10--Carbon-14; 11--Sodium-24; 12--Silicon-31; 13--Phosphorus-32; 14--Sulfur-35; 15--Chlorine-38; 16--Potassium-42; 17--Manganese-56; 18--Iron-59; 19--Copper-64; 20--Fat; 21--Bones; 22-Whole body; 23--Liver; 24--Kidneys.

Table 7.10. Characteristic Data on the Most Important Nuclear Fission Substances in Nuclear Weapons

Radionuklid	Symbol	Strahlungstyp	Halbwertzeit/a	Energie der Alphateilchen E_α/MeV und (Anteil/%)	$E_{\alpha\,(mittel)}$ MeV	Energie der Gammaquanten E_γ/MeV und (Anteil je Zerfallsprozeß/%)
1		2	3	4	5 6	
Thorium-232	$^{232}_{90}Th$	α, γ	$1,4 \cdot 10^{10}$	3,93 (24); 3,99 (76)	3,98	0,059 (24)
13 Uran-233	$^{233}_{92}U$	α, γ	$1,6 \cdot 10^{5}$	4,82 (83,5); 4,77 (14,9) 4,72 (1,6); 4,66 (0,07) 4,58 (0,04); 4,49 (0,03)	4,8	0,056 (0,01) 0,043 (0,05)
14 Uran-235	$^{235}_{92}U$	α, γ	$7,1 \cdot 10^{8}$	4,58 (10); 4,47 (3) 4,40 (83); 4,20 (4)	4,4	0,382 (2); 0,289 (6) 0,184 (40); 0,110 (43) 0,074 (40)
15 Uran-238	$^{238}_{92}U$	α, γ	$4,5 \cdot 10^{9}$	4,18 (77); 4,14 (23) 4,02 (0,1)	4,1	0,112 (0,1) 0,048 (23,1)
Plutonium-239	$^{239}_{94}Pu$	α, γ	$2,4 \cdot 10^{4}$	5,15 (69); 5,14 (20) 5,10 (11)	5,1	0,051 (5,5) 0,038 (5,5)

Radionuklid	$E_{\gamma\,(mittel)}$ MeV	Dosiskonstante k_γ $R\,m^{-2}\,h^{-1}\,Ci^{-1}$	Spezifische Aktivität C/Ci kg^{-1}	Angaben zum Verhalten bei Inkorporation: kritische Organe	biologische Halbwertzeit	effektive Halbwertzeit
		7	8 9	10	11	12
Thorium-232	0,06	0,0068	$1,1 \cdot 10^{-4}$	16 Knochen	200 a	200 a
				17 Gesamtkörper	150 a	150 a
Uran-233	0,04	$2,6 \cdot 10^{-5}$	9,5			
				17 Gesamtkörper	200 d	200 d
Uran-235	0,13	0,09	$2,1 \cdot 10^{-3}$	16 Knochen	300 d	300 d
				17 Gesamtkörper	200 d	200 d
Uran-238	0,05	0,009	$3,3 \cdot 10^{-4}$	16 Knochen	300 d	300 d
				17 Gesamtkörper	200 d	200 d
Plutonium-239	0,04	0,005	60	16 Knochen	200 a	197 a
				17 Gesamtkörper	178 a	175 a

Key: 1--Radionuclide; 2--Radiation type; 3--Half-life, a; 4--Energy of alpha particles E_α MeV, and (share, %); 5--Average; 6--Energy of gamma quantums E_γ, MeV and (share per decay process, %); 7--Dose constant; 8--Specific radioactivity; 9--Date for response of in case of incorporation; 10--Critical organs; 11--Biological half-life; 12--Effective half-life; 13--Uranium-233; 14--Uranium-235; 15--Uranium-238; 16--Bones; 17--Whole body.

7.1.3. Unfissioned part of Nuclear Charge

In addition to the fission products and the neutron-induced radioactivity, radioactive detonation products also include the part of the nuclear charge which is not involved in the reaction. The share of this source of residual nuclear radiation out of the total radioactivity generated during nuclear weapon detonations is not constant but changes as a function of the type of nuclear weapon, the types of energy released, and their contribution to the summary [cumulative] detonation energy, as well as especially the particular nuclear fission efficiency.

In the case of the unfissioned part of the nuclear charge of nuclear fission weapons and three-phase nuclear weapons, we are exclusively dealing with alpha-active radionuclides with long half-life and low specific radioactivities. Although alpha radiation has a great biological effect, the unfissioned part of the nuclear charge therefore as a rule only plays a subordinate role as a source of residual nuclear radiation.

As we can see in Table 7.10, only Pu-239--which is mostly used as nuclear charge for nuclear fission weapons--has a noteworthy specific activity. But here again this kind of radioactivity amount does not turn out to be significant if we start with nuclear weapons in which we want maximum nuclear fission efficiency. The situation is somewhat different in the case of the so-called subcaliber nuclear weapons (Section 1.3.3). Here the alpha radioactivity can be significant with a view of increased danger of incorporation especially after ground and underground detonations in the area around ground zero or the detonation crater and its immediate vicinity. This means basically that measurements and considerations concerning alpha radioactivity are of primary importance wherever there is an objective danger of incorporation of radioactive substances, in other words, in the sector of ration supply, water supply, etc. The need for wearing a mask may arise furthermore also even at comparatively low dose rates. These problems will be covered in greater detail later on.

The gamma radiation accompanying alpha decay process is small in terms of the share and the energy involved and therefore does not make any essential contribution to the cumulative dose rate of the detonation products. This is expressed among other things in the dose constants given in Table 7.10.

In conclusion we might mention that, in the case of three-phase nuclear weapons with a casing of U-238, Pu-239 can also be formed due to neutron capture.

$$^{238}_{92}U + 1n \rightarrow {}^{239}_{92}U \xrightarrow[24\ min]{\beta} {}^{239}_{93}Np \xrightarrow[2,3\ d]{\beta} {}^{239}_{94}Pu$$

But because the action cross-section for this capture reaction is small, one may estimate that the plutonium quantity produced in this way is small.

7.1.4. General Properties of Alpha, Beta, and Gamma Radiation

As we were able to see clearly in sections 7.1 to 7.3, the residual nuclear radiation, emitted by radioactive detonation products, can consist of three components: alpha, beta, and gamma radiation.

Unit operations in radioactively contaminated areas lead to a potential danger of radiation damage, specifically, both due to external radiation and also due to direct incorporation of radioactive substances.

In this connection one must keep in mind that the three developing types of nuclear radiation by virtue of their different physical properties also cause different biological effects. We are particularly interested here in the specific penetration and ionization capacity of the individual nuclear radiation types because their relative degree of danger can be derived from that. In case of external radiation, concerning the threat to man, we get the general sequence of gamma, beta, and alpha radiation; in case of the incorporation of radioactive substances however one must use the exact opposite sequence as basis. This leads us to a series of necessary and possible measures for nuclear radiation protection for units under field conditions; to develop a full understanding of these measures it is necessary here to present some elementary statements on the individual types of nuclear radiation.

7.1.4.1. Alpha Radiation

The alpha radiation (α-radiation) emitted by the unfissioned part of the nuclear charge is a corpuscular radiation. The structure of the alpha particles corresponds to that of the atomic nuclei of the chemical element Helium ($^{4}_{2}H^{++}$). Each alpha particle consists of two protons and two neutrons which are bound to each other with a binding energy of about 7 MeV per nucleon.

Upon each alpha decay, the mass number of the initial nuclide is accordingly diminished by 4 units and the nuclear charge number is diminished by 2 units. That gives us the daughter nuclide in the Periodic System of Elements in each case two digits to the left of the initial nuclide.

In general, the following applies:

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + \alpha$$

Or the following applies for the decay of Pu-239:

$$^{239}_{94}Pu \rightarrow ^{235}_{92}U + \alpha$$

The energy spectrum of alpha radiation of a certain radionuclide is discrete; that is to say, all emitted alpha particles either have the same energy or they can be combined into groups of monoenergetic particles. In the first case, the decay as a rule leads to the basic state of the daughter nucleus while in case of appearance of several "alpha lines" we can get excited states which then fade out along with the emission of gamma quantums.

It is generally customary to illustrate the alpha decay in a term diagram. Here, the energy levels of the atomic nuclei of the initial element and the daughter element and likewise the recognizable intermediate states are characterized by horizontal lines between which the interval is proportional to the energy of these levels.

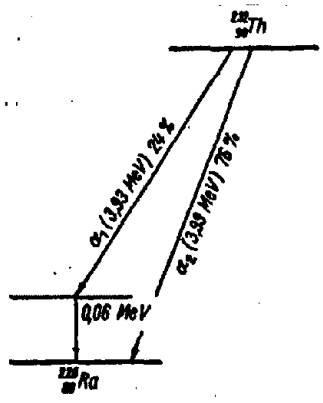


Figure 7.10. Simplified term diagram for Th-232

The energy of the alpha particles, emitted by the unfissioned part of the nuclear charge, is 4-5 MeV. Upon passage through a substance, the alpha particles give off this energy almost exclusively, due to the electrostatic reciprocal effect, to the electrons in the atomic envelope; that is to say, they use them up for ionization. The energy, transmitted on the average to an electron via all substances, is small and amounts to 100-200 eV. In the specific case, the ionizing work to be expended for the formation of an ion pair depends on the type of the irradiated substance.

For air, for example, it only has a value of 32.5 eV (including other marginal processes, it would be 35 eV). This is equivalent to the generation of about 150,000 ion pairs.

The energy of the alpha particles is usually characterized by their range (path, distance) in air (at 15° C and 760 mm Hg). According to the law of Geiger, the range $R_{\alpha(L)}$ of the alpha particles is connected with their initial velocity v_0 by the following relationship:

$$R_{\alpha(L)} = k \cdot v_0^3 \quad \text{cm} \qquad (7.7)$$

Here, k has the value $9.25 \cdot 10^{-28}$ s^3 cm^{-2}. (An initial velocity of $1.5 \cdot 10^9$ cm s^{-1} roughly corresponds to the energy of an alpha particle of 5 Mev.)

The range of alpha particles of equal energy decreases as the density of an absorber increases. It can be determined for substances of differing density from the range in the air with the help of the Bragg-Kelmann rule (accuracy ±15%):

$$R_\alpha = 3 \cdot 10^{-4} \frac{R_{\alpha L)}}{\varrho} A^{1/2} \quad \text{cm} \qquad (7.8)$$

R_α --Range of alpha particle in particular substance, cm
$R_{\alpha(L)}$--Range of same particle in air, cm
ρ--Density of substance, g cm^{-3}
A--Mass number of substance, Me.

Table 7.11. Range R_α of Alpha Particles in Air, in Biological Tissue, and in Aluminum as a Function of their Energy[27]

E_α / MeV	1 in Luft / cm	2 R_α in biologischem Gewebe / µm	3 in Aluminium / µm
4	2,5	31	16
4,5	3,0	37	20
5	3,5	43	23
5,5	4,0	49	26

Key: 1--In air; 2--In biological tissue; 3--Aluminum.

Another possibility for describing the penetration capacity of alpha radiation consists in expressing its range by the surface dimensions of an absorber. (For air, in the energy range of alpha particles of interest here, it is 4 mg cm^{-3}.) This offers the advantage that, in such calculations, we do not need any data as to the density or state of the absorber.

The number of ion pairs, which an alpha particle will form per millimeter of distance in air of 15° C and 760 mm Hg, is called the specific ionization. It averages around 3,000 ion pairs per mm and at the start of the trajectory it is 2,000 ion pairs per mm. This means that the specific ionization goes up toward the end of the range and that it runs through a pronounced maximum just a few millimeters away from the end of the trajectory. After that it decreases again and the alpha particle is converted into a helium atom along with the capture of two electrons.

From what we have said so far, in conjunction with Section 7.1.3, we can draw the following basic conclusions.

Alpha radiation as a component of residual nuclear radiation has a great ionization capability but only a very low penetration capacity. The range of alpha particles in air does not exceed several centimeters and in liquid or solid substances it does not exceed several hundredths of a millimeter. This is why alpha radiation under field conditions is of practically no significance as an outside radiation source. But it is very dangerous in case of incorporation of alpha-active substances and in its immediate action area it is up to tens of times more effective than gamma radiation in biological respects.

We cannot go into any great detail here in covering the measurement technique problems connected with alpha radiation. Reference is made here among other things to the book entitled "Kernwaffenradiometrie und Kernwaffendetonometrie" by Langhans.[28]

Some special questions on the biological effect will be covered in greater detail in Section 7.4.

7.1.4.2. Beta Radiation

By far the greatest part of the radioactive detonation products--fission products and radionuclides induced by neutron radiation--are beta-active. Beta radiation (β-radiation), like alpha radiation, is a corpuscular radiation. Depending upon the type of beta decay, simple-negative-charged or simple-positive-charged particles are radiated with the mass of an electron.

Specifically we therefore distinguish between the negatron decay and the positron decay. Another type of beta conversion is K capture. The two last-named processes however play a completely subordinate role in the context to be examined here and will therefore not be considered in any greater detail.

Negatron-beta decay appears in those radionuclides which reveal a neutron surplus. In the process of this kind of beta decay, a neutron is converted into a proton and a beta particle, with a mass and elementary charge equivalent to an envelope electron, is emitted.

The radiated beta particles, compared to the neutrons and protons forming the atomic nucleus, have only a very small mass; this is why the total mass of the atomic nuclei changes only very little after a beta decay, that is to say, the mass number remains the same.

In general, negatron decay can be illustrated as follows:

$$A + {}_{-1}\beta + {}^{1}_{\nu}{}^{z} \leftarrow X^{z}_{\nu}$$

or we have the following for the decay of the radionuclide Sr-90:

$${}^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + \beta^{-} + \nu$$

In this way, if we have a β^- decay, we each time get the nuclide of a new chemical element which, in the Periodic System, can be found one digit to the right of the initial element.

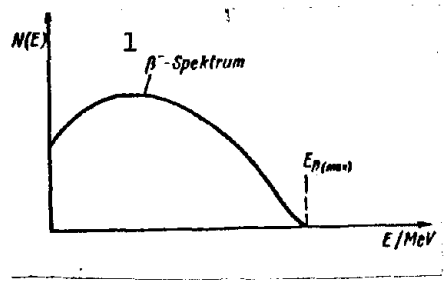


Figure 7.11. Typical shape of β^- spectrum. Key: 1--β^- spectrum.

In contrast to alpha radiation, the beta radiation of a radionuclide reveals a continuing energy spectrum. This can be explained by saying that, upon each beta decay, in addition to the radiated beta particles, an additional particle--a so-called neutrino (ν)--is released. Because of that, the energy released upon the beta decay of a radionuclide is distributed over the beta particle and the neutrino. The proportional energy varies. On the other

hand, the sum of the energy of the beta particle and the neutrino will always be the same for a certain radionuclide, that is to say, it will be characteristic and it corresponds to a certain maximum energy (see tables 7.3 and 7.9).

Individual beta particles have no kinetic energy whatsoever, that is to say, their initial velocity in fact is zero while others come up to 99 percent of the speed of light. The distribution maximum of beta particles generally is between 0.3 E_{max} and 0.5 E_{max}.

A part of the conversion energy is released in the form of gamma radiation also in conjunction with beta decay. While, for example, the radionuclide C-14 is a pure beta emitter, Co-60 is beta-gamma-active.

The average maximum energy of the beta particles of the fission products and of the induced radionuclides changes greatly with the time after detonation and during the first 10 days is to be found in intervals of 2.5 MeV to 0.9 MeV. Although these energy values are considerably below those of alpha radiation, beta radiation nevertheless does have a greater range.

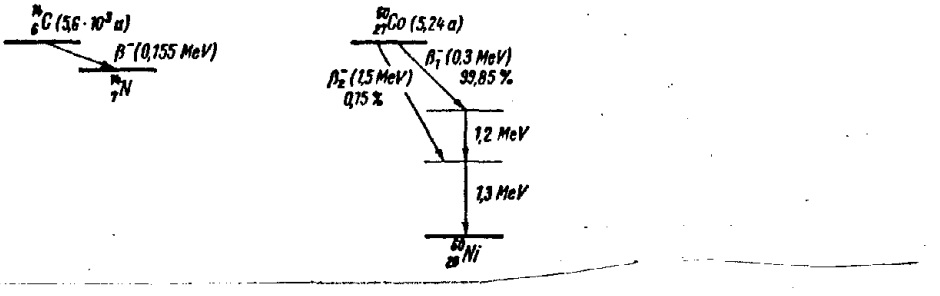


Figure 7.12. Term diagrams for C-14 and Co-60.

The attenuation of beta radiation in a substance takes place almost exclusively due to electrostatic interaction or "collisions" with the envelope electrons. Regarding the effort to be expended for the formation of an ion pair, we get the same conditions as for alpha radiation. But because the ratio between the mass of beta particles and the mass of alpha particles is roughly 1:7,300, the beta particles are strongly deflected from the original propagation direction in conjunction with their interaction with the electrons in the atomic envelopes and do not describe a straight-line movement, like the alpha particles. Because of their considerably faster speed, the specific ionization of beta radiation, at the same energy as that of the alpha particles, however is smaller. It is only on the order of magnitude of 5-10 ion pairs per millimeter of distance in the air. Although beta radiation consumes most of its energy due to a large number of ionization processes, the energy loss due to braking and scattering of beta particles, due to the effect of electrical fields of the atomic nuclei, must not be disregarded. In this interaction between negatively-charged beta particles and the positively-charged atomic nuclei, we get x-rays as "braking radiation." This energy loss can come close to the part of the energy of beta radiation, which is consumed by ionization processes, in substances with a high mass number.

From the fact that beta radiation reveals a continuing energy spectrum it follows that the range of the individual beta particles of one and the same beta-active radionuclide will differ. This is why the intensity of beta radiation upon passage through an absorber declines gradually and within certain limits follows an exponential attenuation law.

To estimate the maximum range of beta radiation of a given energy, we can use the approximation formulas developed by Feather. The following applies accordingly:

$$R_{\beta\,(max)} \approx \frac{0{,}407 E_{\beta\,(max)}^{1{,}38}}{\varrho} \quad \text{cm} \tag{7.9}$$

and for $E_{\beta(max)} > 0{,}8$ MeV

$$R_{\beta\,(max)} \approx \frac{0{,}542\, E_{\beta\,(max)} - 0{,}133}{\varrho} \quad \text{cm} \tag{7.10}$$

$R_{\beta\,(max)}$--Maximum range of beta particles, cm
$E_{\beta\,(max)}$--Maximum energy of beta particles, MeV
ρ--Density of absorber, g cm^{-3}

Another possibility of describing the range or penetration capacity of beta radiation, as in the case of alpha radiation, consists in the introduction of the surface dimensions [surface mass]. But here, in determining the "practical range" we start with that surface mass [dimension] through which only 1 percent of the beta particles will pass. Two empirical formulas have been established in this connection. The approximation formula according to Flammersfeld applies in the area of a maximum beta radiation energy of 0-3 MeV.

$$R_{\beta(max)} = 0{,}11 \left(\sqrt{1 + 22{,}4\, E_{\beta(max)}^2} - 1\right) \quad \text{g cm}^{-3}$$

The approximation formula according to Bleuer and Zuenti applies when $E_{\beta(max)} > 1$ MeV.

$$R_{\beta(max)} = 0{,}571\, E_{\beta(max)} - 0{,}161 \quad \text{g cm}^{-3} \tag{7.12}$$

The energy must be inserted in terms of MeV in both numerical equations.

When we use formulas 7.9-7.12, we must keep in mind that considerable errors are possible due to the self-absorption of low-energy beta particles in the detonation product mixture or due to the back-scatter from a support.

One must for example expect that, if we have a steel surface contaminated by radioactive dust, more than 30 percent of the beta particles radiated toward the support will be scattered back.

Table 7.12. Maximum Range $R_{\beta(max)}$ of Beta Particles in Air, in Biological Tissue, and in Aluminum as a Function of their Energy[29]

1	2	3
$E_{\beta(max)}$ MeV	$R_{\beta(max)}$ in Luft cm	in biologischem Gewebe mm	in Aluminium mm
0,1	10,1	0,158	0,050
0,2	31,3	0,491	0,155
0,3	56,7	0,889	0,281
0,4	85,7	1,35	0,426
0,5	119	1,87	0,593
0,6	157	2,46	0,778
0,7	186	2,92	0,926
0,8	231	3,63	1,15
0,9	261	4,10	1,30
1,0	306	4,80	1,52
1,25	406	6,32	2,02
1,50	494	7,80	2,47
1,75	610	9,50	3,01
2,0	710	11,1	3,51
2,5	910	14,3	4,52

Key: 1--In air; 2--In biological tissue; 3--In aluminum. Note: The values given for biological tissues can also be used for water.

In combination with the statements in sections 7.1.1. and 7.1.2. we can say the following by way of summary.

Beta radiation as a component of residual nuclear radiation has a relatively low ionization capacity but a considerably greater penetration capacity than alpha radiation. The practical range of the beta particles in air amounts to several meters, in biological body tissue it amounts to several millimeters, and in denser materials it amounts to a few millimeters. This is why beta radiation, like alpha radiation, primarily constitutes a danger in case of incorporation or also when the beta-active materials directly reach the skin, especially the mucosae. As outside radiation it is of less interest under combat conditions because it is mostly absorbed by clothing and protective gear and is kept away from radiation-sensitive body parts.

As the age of the fission product mixtures increases, there is also an increase in the relative biological danger from beta radiation because of the enrichment in long-lived radionuclides. This is why one cannot take absolute radioactivity as the sole criterion for possible damage to persons. In case of nuclear weapon detonations outside the dense atmosphere, the beta particles (electrons) form artificial radiation belts (see Section 6.4) which can continue for hours and days and in unusual cases even considerably longer.

If a space weapon flies through such a radiation belt, there will be a very hard braking radiation (x-rays) during the process of braking of the beta particles, which can damage human beings or which can also destroy electronic components or put them out of action.[30]

7.1.4.3. Gamma Radiation

Many alpha-active and beta-active radionuclides are still excited after the emission of alpha particles or beta particles and emit this surplus "residual energy" in the form of gamma radiation.

Gamma radiation (γ-radiation) is an electromagnetic wave radiation. It consists of individual quantums (energy packages) of a certain energy. Like any electromagnetic radiation, gamma radiation is propagated at the speed of light.

The gamma radiation emitted by a certain radionuclide is characteristic for it because it is not distributed over a continual energy spectrum but rather because the individual gamma quantums have very specific discrete energies. For example, the radionuclide Al-27 upon each beta decay emits a gamma quantum with an energy of 1.8 MeV, the radionuclide Na-24 emits two gamma quantums with an energy of 1.37 or 2.75 MeV.

The gamma spectrums of the radionuclides of fission products or radioactive detonation products in general however in many cases are more complicated and partly are not yet fully known.

Because the gamma quantums, in contrast to the alpha and beta particles, have neither a rest mass nor an electric charge, their interaction with a substance is also quite different. While the charged alpha and beta particles transmit their energy in portions to the envelope electrons in the course of many individual ionization processes, the gamma quantums give off their total energy either in one act or in a few reciprocal processes. But there is little probability that there will be such a reciprocal interaction, contributing to the attenuation of gamma radiation, per unit of distance, with the electrons of the atomic envelope. This is why the gamma quantums have a great range as a function of their energy.

Because the reciprocal processes between gamma quantums and the envelope electrons were explained in detail already in the description of instantaneous nuclear radiation in Section 5.3.1, something which as we know involves the Compton, photo, and pair formation effects, we need not go into this problem complex in any greater detail here.

Concerning attenuation in an absorber, gamma radiation strictly follows the exponential law:

$$I_\gamma = I_{0,\gamma} \cdot e^{-\mu d} \qquad (7.13)$$

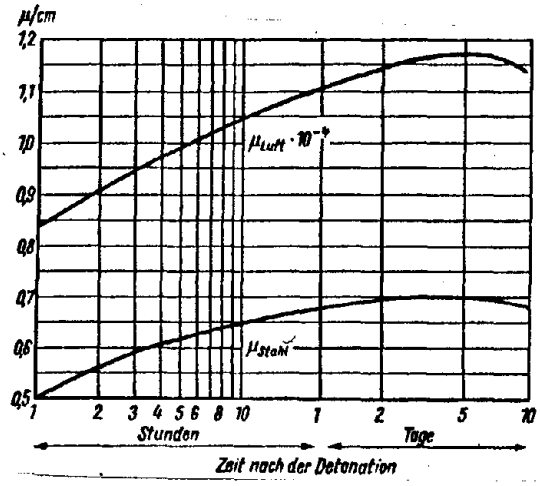


Figure 7.13. Reference values for the linear attenuation coefficient μ of gamma radiation from fission products as a function of the time after detonation. Key: 1--Hours; 2--Days, 3--Time after detonation; 4--Air; 5--Steel.

For practical calculations, we can use the formulas in Section 5.3.2.1. But because the average energy of gamma radiation of residual nuclear radiation differs from that of instantaneous nuclear radiation and because it also changes with the passage of time after detonation, we must insert the corresponding values both for the linear attenuation coefficients and for the effective half-life layers.

Section 7.3 will in greater detail cover some problems resulting from the fact that the radioactive detonation products are present as area source.

Summarizing, we can say this:

Gamma radiation as a component of residual nuclear radiation has extraordinarily great penetration capacity. It therefore can act even on crew members in armored combat vehicles and on persons in shelters. During combat operations in radioactively contaminated areas it represents the absolutely greatest danger in the form of outside radiation.

This is why, under field conditions, the computations for the evaluation of the nuclear radiation situation are primarily based on the dose rate or the dose of gamma radiation.

Review Questions

7.1. What are the factors that, after nuclear weapon detonations, determine the quantity and properties of the developing radioactive detonation products? Describe the three types of radioactive detonation products.

7.2. Describe the most important properties of the fission product mixture and interpret the data in Table 7.3.

7.3. How do the cumulative activity and the cumulative dose rate of fission products change with the passage of time after detonation? What is the significance of the assumption of a direct proportionality between the change in radioactivity and in the dose rate?

7.4. What practical conclusions spring from the constant change in the composition of the fission product mixture?

7.5. Why do certain difficulties come up in an attempt at a generalizing evaluation of neutron-induced radioactivity? What do they consist of?

7.6. Explain the principle of neutron capture.

7.7. What radionuclides can the induced radioactivity of air, water, and the soil be primarily traced back to? Interpret the data in Table 7.9.

7.8. What differences result between the fading of radioactivity of fission products and that of the induced radionuclides in the soil? Compare the energy ratios.

7.9. What peculiarities result from underground detonations regarding the composition and distribution of radioactive detonation products?

7.10. What is the significance of the unfissioned part of the nuclear charge regarding the overall radioactivity and the overall effect of the radioactive detonation products.

7.11. Describe the fundamental properties of alpha, beta, and gamma radiation.

7.12. Why do we get a different sequence in the case of external radiation and in the case of incorporation regarding the relative biological danger deriving from the individual types of nuclear radiation?

7.2. Propagation and Distribution of Radioactive Detonation Products

7.2.1. Radioactive Fallout Zones

In almost all detonation types, a more or less large part of the radioactive detonation product is expelled into the earth's atmosphere. The phenomena of the propagation and distribution of these detonation products are very multilayered and complicated. Depending on the prevailing high-altitude weather situation, the radioactive particles can cover large distances during short intervals of time. The composition and concentration of radioactive detonation products in the atmosphere as well as their geographic distribution constantly change in the course of these processes. All of these processes are very closely tied to the dynamics of the general zonal circulation of the earth's atmosphere. This is why the prognosis or evaluation of the radioactive contamination of the terrain resulting from nuclear weapon detonations is not only a physical but much more a weather problem in the broadest sense.

To describe the overall process of radioactive fallout from nuclear weapon detonations, a large number of general and special theories and models was developed in recent years.[31] Nevertheless, the current status of fallout prediction is not yet satisfactory and many problems remain to be solved. However, in this section it is neither our intention to develop a "general

theory" of radioactive precipitation, nor do we want to intrepret many statistics needed in evaluating radioactive contamination of terrain. Instead, the following statements center around those problems which characterize the significance of residual nuclear radiation as a possible main annihilation factor and their full understanding is absolutely necessary to derive the corresponding conclusions for the protection of units in case of operations in radioactively contaminated areas. This objective starts with the idea that it is impossible under the conditions of a complicated nuclear radiation situation to tie the commanders to simple and rigid rules as they make their decisions--without understanding the overall interrelationships.

Many factors influence the character of radioactive contamination of the atmosphere and the earth's surface. They include the following:

The detonation intensity and the detonation type of a nuclear weapon;

The cumulative initial radioactivity of the radioactive detonation products and their decay during the passage of time after detonation;

The distribution of radioactivity in the form of radioactive particles in terms of size and altitude at the moment of the detonation cloud's stabilization.

The direction and velocity of high-altitude winds that influence the propagation of the detonation cloud and the fallout of radioactive particles from it at the moment of detonation and at the place of detonation and in the course of its propagation at the particular places and the particular times;

The appearance of natural precipitation in the form of rainfall or snow which can speed up the deposit of radioactive substances;

The influence of vertical air currents as well as the terrain relief and the vegetation cover on the distribution of radioactive substances.

It is primarily that part of the radioactive detonation products which contributes to the radioactive contamination of the atmosphere and then of the earth's surface which initially is in the fireball and later on in the detonation cloud and which rises with them.

Depending on the nuclear weapon's detonation type and detonation intensity (see Section 2.1.2), the radioactive detonation products thus get directly or indirectly into the troposphere and into the stratosphere and are stored here for some time.[32] The subsequent fallout of radioactive particles and their deposit on the earth's surface lead to the development of radioactive precipitation areas with differing surface radioactivity and dose rate.

The radioactive contamination of the earth's surface caused by nuclear weapon detonations can schematically be subdivided into three fallout zones: the zones of local (direct), continental (semiglobal), and global radioactive fallout.

The zone of local radioactive precipitation, which takes effect during the first few hours and days after a nuclear weapon detonation, includes the radioactive contamination of the immediate detonation area and in the terrain in the direction in which the detonation cloud moves off (radioactive trace) up to those distances at which there is potentially a danger of radiation damage to man in case of brief stay in the area.

The zone of radioactive fallout [precipitation] covers a deposit region all around the globe at the level of the particular geographic latitude of the detonation with an average width of 2,000-3,000 km.

For the local and continental fallout it is especially the processes taking place in the troposphere that are of interest. Radioactive particles in the troposphere fall back to the earth's surface within a few months. The bulk of the radioactive detonation products is concentrated in the lower part of the troposphere (up to about an altitude of 6 km). The size of the particles contributing to continental fallout is 1-5 μm.

The zone of global radioactive fallout covers large parts of the earth's surface or the entire surface of the earth. It is caused by that part of the radioactive detonation products which get into the stratosphere. Concerning worldwide stratospheric fallout it is typical that the detonation products are stored for a longer time (years) in the stratosphere, that they enter the tropopause relatively slowly, and that they are deposited from there on the earth's surface and that a homogeneous mixture of long-lived radionuclides is developed with the passage of time. The separation of the radioactive detonation products from the stratosphere depends on the geographic latitude and reveals a seasonal pattern (maximums in the middle latitudes and in the spring, minimums along the Equator and in the autumn). Both phenomena are closely tied to the average zonal wind movement. Stratospheric fallout consists of the very smallest particles (d < 1μm).

The disruption of radioactive detonation products over the local, continental, and global radioactive fallout depends primarily on the type of detonation and the detonation intensity. Data in the literature vary greatly on that score.[33] Some figures are nevertheless given in Table 7.13.

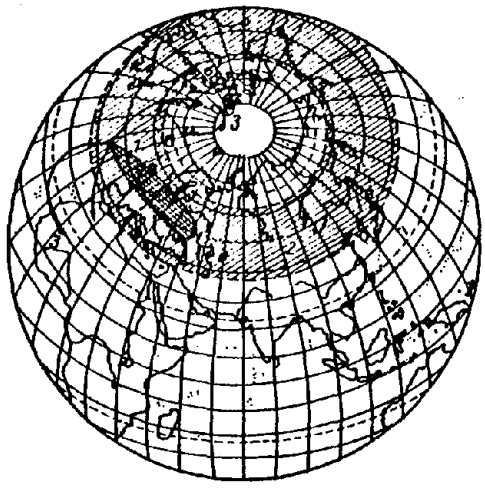


Figure 7.14. The zones of local (1), continental (2), and global radioactive fallout (3) after nuclear weapon detonations.

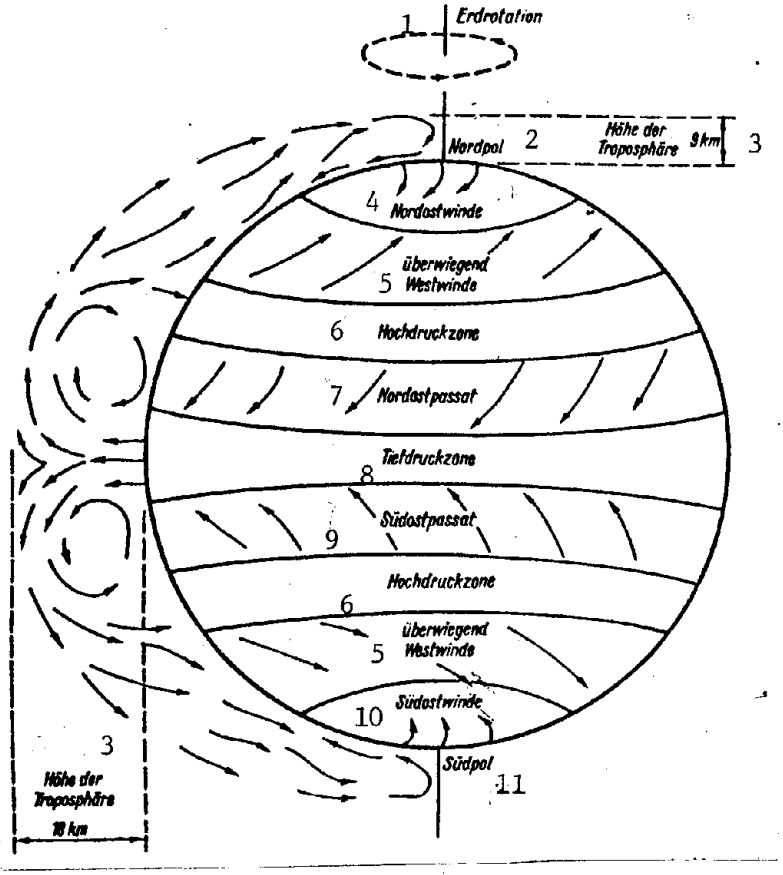


Figure 7.15. Simplified diagram illustrating the zonal circulation of the earth's atmosphere.[34] Key: 1--Earth's rotation; 2--North Pole; 3--Altitude of troposphere; 4--Northeast winds; 5--Prevailing west winds; 6--High-pressure zone; 7--Northeast tradewind; 8--Low-pressure zone; 9--Southeast tradewind; 10--Southeast winds; 11--South Pole.

Table 7.13. Distribution of Radioactive Detonation Products over the Individual Fallout Zones as a Function of the Type of Detonation and Detonation Intensity

1 Art der Detonation	2 Anteil am Gesamtniederschlag/% 3 lokaler Niederschlag	4 kontinentaler Niederschlag	5 globaler Niederschlag
6 Höhendetonationen	–	–	100
7 hohe Luftdetonationen			
8 kt-Bereich	1	9	90
9 Mt-Bereich	–	1	99
10 niedrige Luftdetonationen	10	30	60
11 Erddetonationen			
8 kt-Bereich	70	20	10
9 Mt-Bereich	60	20	20
12 Wasserdetonationen			
8 kt-Bereich	20	60	20
9 Mt-Bereich	20	10	70
13 unterirdische Detonationen (mit äußerer Wirkung)	80	20	–

Key: 1--Type of detonation; 2--Share out of total fallout, %; 3--Local fallout; 4--Continental fallout; 5--Global fallout; 6--High-altitude detonations; 7--High-altitude air bursts; 8--kt range; 9--Mt range; 10--Low-altitude air bursts; 11--Ground bursts; 12--Water detonations; 13--Underground detonations (with external effect).

Figure 7.15 illustrates the zonal circulation in the earth's atmosphere in a greatly simplified manner. This overall circulation however is disturbed in that individual high-pressure and low-pressure regions take shape over various areas on the earth's surface. Because, as we know, the air masses are generally shifted from areas of high air pressure to areas of low air pressure, we get spatially differing air currents with varying directions and intensities.

Regardless of that we can say that the Central European area is located in a zone with prevailing winds from the western directions (about 75 percent for annual average) with an average velocity of 40-50 km hr^{-1}. This leads to the conclusion that there is a great probability that we have a general propagation tendency for the radioactive traces running a west-east direction.

The average wind velocities have a tendency to increase with the altitude. This increase is generally typical but it varies for the individual geographic latitudes and seasons. Because of that, radioactive detonation products generally spread all the faster, the higher the detonation cloud rises; that is to say, the greater particular detonation intensity is (Figure 7.16).

The radioactive particles of the detonation products which constitute continental fallout circle the globe once in about 4-7 weeks, in a west-east direction, in the middle latitudes.

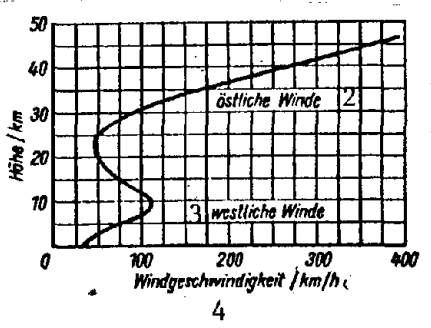


Figure 7.16. Average wind velocity as a function of the altitude over the earth's surface for the middle geographic latitudes.[35]
Key: 1--Altitude; 2--East winds; 3--West winds; 4--Wind velocity, km/hr.

On 1 March 1955, the United States on the Nevada test range conducted a nuclear weapon detonation in the Megaton range. As a result of that test, radioactive fallout came down over England between 8 and 10 March, over Greece and Turkey on 11 March, in the European part of the Soviet Union on 13 and 14 March, and in the Far East of the Soviet Union on 16-19 March.

At the end of 1963, after the entry into force of the Agreement on the Suspension of Nuclear Weapon Tests in the Atmosphere, in Outer Space, and under Water, signed by the Soviet Union, the United States, and Great Britain, the total radioactivity of the stratosphere in the northern hemisphere of the globe was something like 20 MCi and then dropped steadily (if one disregards the tests conducted by France and China). Data on the average time spent by radioactive particles in the stratosphere are presently still contradictory. It was assumed originally that annually only about 10 percent of the radioactive particles present in the stratosphere would again reach the earth's surface within a year; more recent research results show that the average half-life periods, at altitude of more than 25 km, are between 2 years (polar regions) and 4 years (Equator region) and that they are analogously between 0.5 and 3 years at altitudes below 25 km.

It is typical of continental fallout but even much more so of stratospheric global fallout that it involves mostly long-lived radionuclides (for example, Sb-125, Ce-144, Pm-147, Sr-90, Y-90, Rh-106, Ru-106, Cs-137). The composition of the radionuclide mixture in the atmosphere changes only in the course of radioactive decay processes.

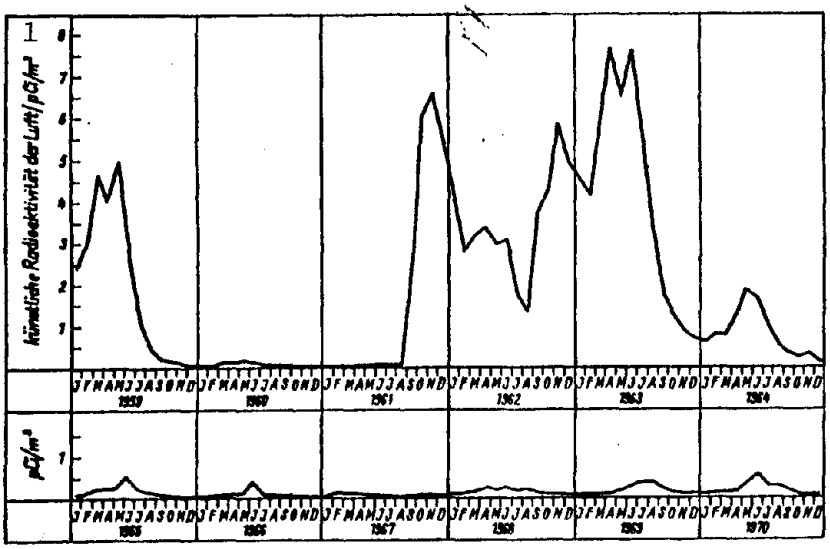


Figure 7.15. Radioactivity in the air layer near the ground in the GDR, caused by nuclear weapon detonations, in the years 1959-1970 (mean value from measurements at nine stations).[36] Key: 1--Artificial radioactivity of the air, pCi/m^2.

The global deposit of radioactive detonation products does not take place uniformly but reveals a dependence on the geographic latitude. The concentration in the northern hemisphere is considerably greater than in the southern hemisphere. According to available data, the maximum is to be found in the middle northern latitude. The biggest threat from worldwide radioactive fallout resides in the enrichment of certain long-lived radionuclides through biocycles in the human body.

Once reaching the earth's surface, the radioactive substances are absorbed by the upper ground layers, they are taken in by the plants in the process of metabolism, and they thus get directly from the plant into the human body or only through a detour via the animal body or the animal product (for example, milk). Other incorporation sources are the consumption of radioactive water and the inhalation of radioactively contaminated air.

During periods of increased nuclear weapon tests in the atmosphere, the "underground radiation" in various parts of the world subsequently increased by more than 50 percent compared to the natural radiation level. The content of strontium-90 in the bones of English pasture sheep in 1954-1956 rose from one to six units. The average strontium-90 content of milk in the United States rose from 4 units in 1954-1955 to 5-9 units in 1957 and, if nuclear weapon tests had been continued in the atmosphere unhindered, it would have reached a value of 20-30 units in 1970.

As we know, strontium-90 is enriched particularly in the bone. Because it is close to calcium in chemical respects, it gets into the body skeleton via the same routes as the latter. The beta radiation emitted here by strontium-90 among other things can lead to leukemia, bone sarcomas, and cancer because the bone marrow is one of the most radiation-sensitive tissues of the human body.

The accumulation of strontium-90 and cesium-137 can cause an increase in the irridiation of germ cells. This can cause the birth of children who will suffer from so-called incurable inherited diseases (diseases of the CNS, the hematopoietic system, appearance miscarriages [monsters], etc.).

These are just a few examples which however are suitable in clearly presenting the overall problem complex of the global radioactive contamination of the earth.[37]

From the military angle we are interested above all in local radioactive fallout within the context given here. This is why we will in the following segment take a detailed look at local terrain contamination as a function of the type of detonation.

7.2.2. Local Radioactive Terrain Contamination as a Function of the Type of Detonation

7.2.2.1. Radioactive Terrain Contamination after Ground Bursts

7.2.2.1.1. General Viewpoints

After ground bursts, the radioactive contamination of the terrain becomes a main annihilation factor. Due to the fireball's contact with the ground, a part of the soil or other materials found there will melt or will be vaporized at the place of detonation and is swept up into the fireball. This is why there is a close mixing of the radioactive detonation products in the fireball with slag, dust, and water vapor.

As the fireball cools off and as the detonation cloud is formed (condensation cloud), the nonvolatile radionuclides will be condensed first, followed later by the volatile ones. The gaseous fission products escape condensation. But among the noble gases, we find some radionuclides with an extremely short half-life whose daughter products are nonvolatile and therefore are condensed immediately after they develop. Radioactive aerosol particles of differing size are formed already as a result of these processes. Due to the effect of turbulent air currents, smaller particles can be deposited together with larger ones. This coagulation capacity depends among other things on the chemical and physical structure of the particles.

In addition we have the reciprocal interaction between radioactive particles and the inactive admixtures of the fireball or the detonation cloud. These particles in the first group originate from the condensation of the vaporized soil. They include the nonvolatile radionuclides and are more or less homogeneously distributed.

In contrast to that, the particles in the second ground have a quasicrystalline structure (at most only the surface is melted) and they are radioactive because of the deposit of easily volatile radionuclides and their daughter products. This among other things can be explained by saying that the rapid rise of the fireball and the attendant suction causes additional quantities of earth masses to be swept up from the crater and its immediate vicinity

and all this material likewise gets into the condensation cloud to a certain extent. The detonation cloud's stem develops in this fashion.

The detonation cloud from a nuclear weapon detonation contains particles of differing size and physical as well as chemical structure due to complicated processes. The particle size spectrum is in the range of 0.01-1,000 μm. The share of particles of a certain size category cannot be clearly fixed and depends very much on the specific detonation conditions.

By way of reference values one may assume that, in case of ground bursts, the mass of radioactive particles will have diameters between 50 μm and 200 μm. After air bursts, about 90 percent of the particles will have a diameter of $d < 10$ μm. But it is not true that the large particles also contain the major portion of radioactivity. Instead, the overall radioactivity is distributed unevenly over the individual size categories. After ground bursts, about 12 percent of the initial radioactivity are found in particles with a diameter of $d \geq 200$ μm, 30 percent have a diameter of $200\ \mu m > d \geq 100\ \mu m$, 38 percent have particles with a diameter of $100\ \mu m > d \geq 50\ \mu m$, and 20 percent have a diameter of $d < 50$ μm.

The particle size of the radioactive detonation products in the detonation cloud decreases from the base of the cloud toward the peak. About 10-20 percent of the total radioactivity are concentrated in the "stem," the rest is found in the "mushroom cap" of the detonation cloud.

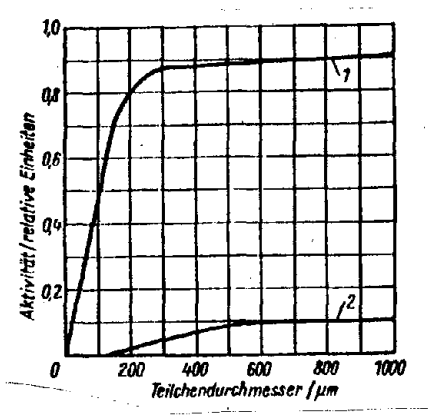


Figure 7.18. Radioactive contamination distribution as a function of the particle size in the "condensation cloud" (1) and in the "stem" (2) of the detonation cloud.[40]
Key: 1--Radioactivity, relative units; 2--Particle diameter, μm.

Particles which are bigger than 1 mm will fall back to the earth directly in the detonation area and in its vicinity. As for the rest, the fallout process is an extraordinarily complicated phenomenon. Zier points out that, according to the law of Stokes, spherical particles with the density of water require about 50 minutes to fall through the troposphere from an altitude of 12 km with a diameter of 1,000 μm, about 10 hours when $d = 100$ μm, about 1 month when $d = 10$ μm and about 10 years when $d = 1$ μm.[38]

But the density of the radioactive particles is about 2.2-2.8 times the density of water. This results in a faster fallout velocity.

In practical radiation calculations however one treats the entire radionuclide mixture according to the laws of fission products. As a result of this we can observe that the dose rate of gamma radiation during the first few hours after the detonation fades somewhat more slowly than described by the $t^{-1.2}$ law. The initial dose rates appearing near ground zero or in the area of the crater are so high that even a short stay outside shelters can lead to severe radiation damage or to the absorption of a lethal dose.

The shares out of the total radioactivity, which, after a ground burst, can be found in the detonation area or the radioactive trace, are determined not only by the factors already mentioned but also by the soil structure. Thus the diameters of the radioactive particles, which develop after detonation over or on sandy soils, on the average are definitely greater than those over clayey or rocky soils.

Up to about 20 percent of the radioactive detonation products, mostly from the cloud's stem, during the latter's upward movement will fall back into the detonation area during a period of 5-10 min. In this connection, the air layer near the ground is heavily contaminated with radioactive dust for a period of up to 30 min and more.

In evaluating the terrain's radioactive contamination in the detonation area, one must furthermore keep in mind that an "additional" superposition by the radioactive trace takes place in the effective wind direction. This is why the maximum dose rates of gamma radiation differ essentially at identical distances from ground zero at the side facing toward the wind and at the side of the detonation area facing away from the wind. Some reference figures are given for the first-named area in the following graph (Figure 7.23). For comparison, the analogous values are also entered for the detonation area of a low-level air burst. They apply to the entire detonation area.

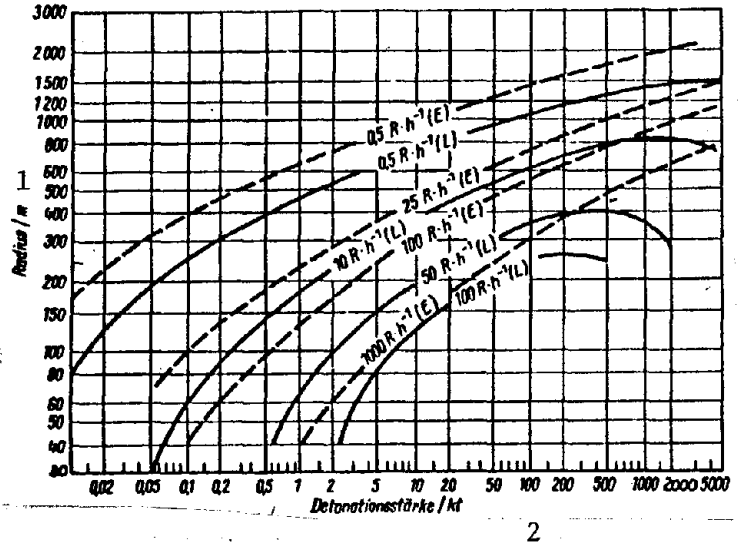


Figure 7.23. Radii of radioactively contaminated zones with a certain dose rate in the area of a ground burst (on the side facing toward the wind) and in the area of a low-altitude air burst, related to 1 hour after the nuclear weapon detonation.[42]
Key: 1--Radius; 2--Detonation intensity.

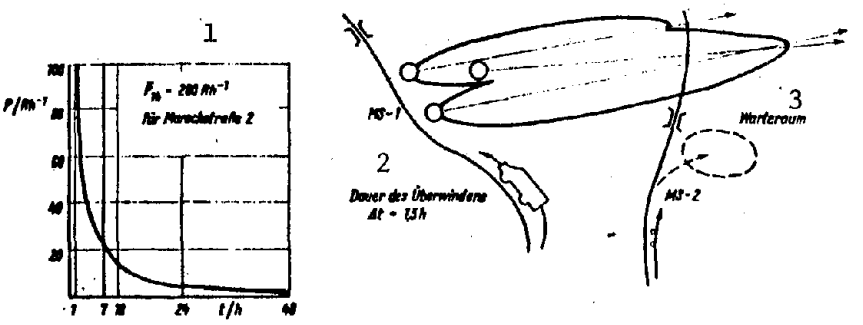
Table 7.18. Mean Values of Residual Nuclear Radiation Protection Factors for Various Objects

Type of Object	Protection factor
Foxholes	0.1
Trenches, open, not decontaminated	0.3--0.5
Trenches, open, decontaminated	0.05
Trenches, covered, not decontaminated	0.1
Trenches, covered, decontaminated	0.04
Shelters, light-weight type	0.03
Shelters with dirt cover of more than 1 m	<0.001
Wooden houses	0.3
Stone houses, one story	0.1
Stone houses, two stories	0.05
Stone houses, three stories	0.03
Stone houses, more than three stories	<0.01
Motor vehicles	0.5
APC's	0.25
Tanks	0.1
Railroad cars	0.3
Aircraft	0.5

To make this presentation shorter, we will also briefly explain some additional problems with the help of examples which the reader can accordingly vary or interpret if he works along with us actively. The calculation methods generally are outlined only briefly. In this connection reference is made to the mathematical setup in Section 7.3.

Example 1

Crossing contaminated zones and waiting for the dose rates to decline (Figure 7.39).



4 Tabelle der Strahlungsbelastung (gerundete Werte)

Variante 1 5 Überwinden der „neuen" Spur				Variante 2 6 Überwinden der „alten" Spur			
7 beim Überwinden nach	8 Dosisaufnahme / R mit 9 Pz	SPW	Kfz	7 beim Überwinden nach	8 Dosisaufnahme / R mit 9 Pz	SPW	Kfz
1h	15	30	75	1d	0,6	1,5	3
5h	3	8	15	1,5d	0,45	1	2,5
10h	1	3	5	2d	0,3	0,7	1,5

Figure 7.39. Key: 1--For march route 2; 2--Duration of crossing; 3--Standby area; 4--Radiation exposure table (figures rounded); 5--Variant 1, crossing the "new" trace; 6--Variant 2, crossing the "old" trace; 7--In case of crossing after; 8--Dose exposure/R; 9--With; Pz--Tank; SPW--APC; Kfz--Motor vehicle.

(In the example selected, all time indications refer to the average timing of the three nuclear weapon detonations. As the calculation value for march route 2 we assumed a dose rate of P = 200 R/hr^{-1} when t = 1 hr after detonation.)

The table clearly shows that, when getting through a newly contaminated zone, in other words, during the first hours after the formation of the trace, even a brief delay of the start of the crossing movement will lead to a considerable reduction in the radiation exposure of the troops. On the other hand, in the case of old traces (variant 2), the exact moment of crossing the area is of less interest.

The numerical figures calculated furthermore clearly show that the state of protection plays a great role during the crossing move. One must however not draw any hasty conclusions from this fact. First of all one must keep in mind that we may have mixed convoys in a whole series of cases or that we might have convoy parts in a particular march movement order with different protection factors. Besides, while crossing the area, the unit may be forced to stay there longer also in heavily or dangerously contaminated zones due to enemy action or due to demolition and the blocking of march routes, due to fires, floods, etc. In this case the radiation exposure (variant 1) rises rapidly and can even lead to the loss of combat capacity. In our example, an additional stay of 1 hour will increase the dose absorption during the crossing time interval from 1 to 10 hours by 10-130 R.

Example 2

On leaving or staying in a contaminated area (Figure 7.40)

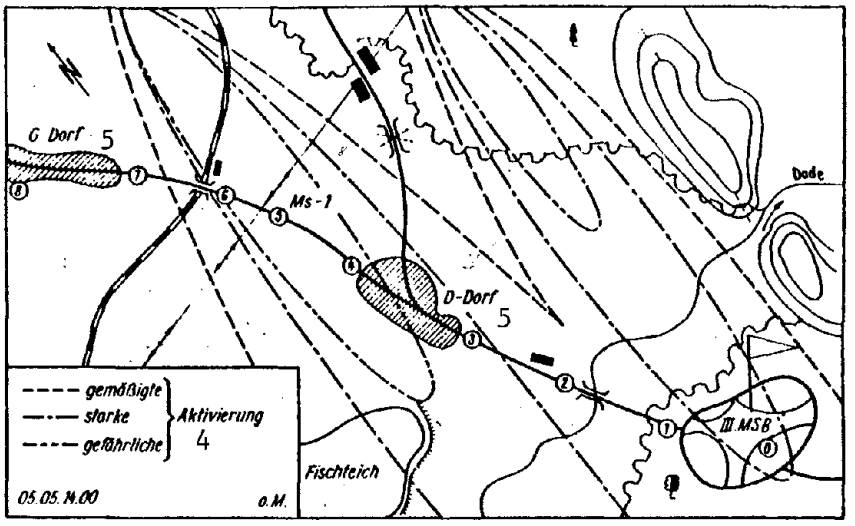


Figure 7.40a Key: 1--Moderate; 2--Heavy; 3--Dangerous; 4--Contamination; 5--Village; 6--Fish pond; MSB--Motorized Rifle Battalion.

1

Meßpunkt-Nr.	0	1	2	3	4	5	6	7	8
P/Rh^{-1}	20	10	15	25	45	75	40	5	1

2

Auskunftsangaben

Beginn des radioaktiven Niederschlags im Ausgangsraum des III. MSB : 13.00 Uhr;
Länge der Marschstrecke Ausgangsraum – Westausgang G-Dorf : 30 km;
Mittlere Marschgeschwindigkeit : 15 km h^{-1};
Mittlere Dosisleistung der Marschstrecke $\bar{P}_{2h} \approx 25$ Rh^{-1}, des Ausgangsraumes $\bar{P}_{2h} = 20$ Rh^{-1};
Berechnungsgrundlage für den Marsch : SPW mit $f_s = 0{,}25$ bzw. Kfz mit $f_s = 0{,}5$, für den Ausgangsraum: abgedeckte Gräben mit $f_s = 0{,}1$

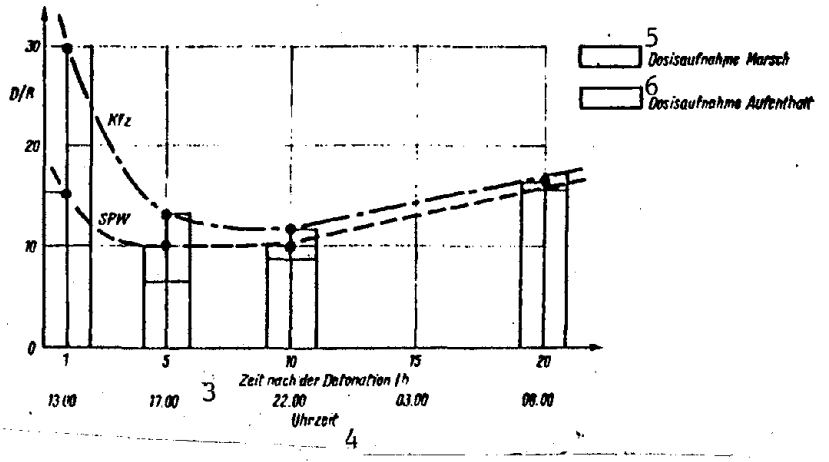


Figure 7.40b. Key: 1--Measurement point number; 2--Informational data: start of radioactive fallout in jump-off area of 3 MSB: 1300; length of march route

[Key continued on following page]

[Key to Figure 7.40b continued] from jump off area to western exit of G-village 30 km; average march movement speed: 15 km/hr^{-1}; average dose rate on march route $\bar{P}_{zh}$ = 25 R/hr^{-1}, of jumpoff area, $\bar{P}_{zh}$ = 20 R/hr^{-1}; calculation base for mach movement: APC with f_s = 0.25 or motor vehicle with f_s = 0.5, for jumpoff area: covered trenches with f_s = 0.1; 3--Time after detonation, hrs; 4--Clock time; 5--Dose absorbed during march movement; 6--Dose absorbed during break; Kfz--Motor vehicle; SPW--APC.

In the example calculated here, where the required informational data are already given, we can clearly see that the best time interval for moving the 3rd MSB out of the jumpoff area on march route 1 toward G-village is between 1700 and 2200, that is to say 5-10 hours after the detonations. The dose rate level, other things being equal, in fact does not have any influence on the position of this time interval, apart from extreme differences in the average dose rates in the jumpoff area and on the march route. The decisive thing instead is primarily the ratio between the protection factors of the shelters in the jumpoff area and those of the combat vehicles. The better the jumpoff area has been developed and improved by the Engineers, the later should we leave it in order to minimize the troops' radiation exposure. Such assignments of course cannot be exactly figured out completely as a rule under field conditions but they can be rapidly accomplished at least by means of an uncomplicated comparison calculation.

Example 3

Determination of average dose rate for march routes (Figure 7.41).

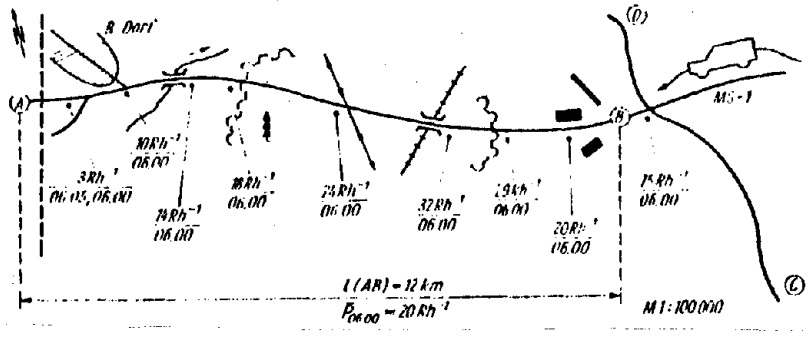


Figure 7.41.

Dose calculations for unit operations in contaminated zones frequently as the first step require the conversion of the measured dose rates to a uniform semistrategic reference time while the second step involves the determination of an average dose rate for a march route, a direction, or an area. Such calculations must always be connected with an evaluation of the information content of the initial magnitudes in order from the very beginning to prevent any kind of playing with numbers. The computation method to be selected must in particular take into account the density of measurement points and the relative differences in the dose rates. Specifically, the calculations can be performed according to three methods.

Assuming that we only have very sketchy reconnaissance reports, although the maximum dose rate of a sector of a radioactive trace to be crossed may be known, the following empirical relation applies:

$$D = \frac{0{,}25 \cdot P_{max} \cdot l \cdot f_0}{v_M} \quad R \qquad (7.47)$$

l--Length of contaminated sector, km
f_0--Protection factor of combat vehicle (Table 7.18)
v_M--March movement speed, km/hr^{-1}

If we have a relatively uniform measurement point density and if the dose rates do not differ too much from each other with the distance, then we can use the following formula:

$$D = \frac{\bar{P} \cdot l \cdot f_0}{v_M} \quad R \qquad (7.48)$$

whereby we get the average dose rate $\bar{P}$ from the following:

$$\bar{P} = \frac{P_1 + P_2 + \cdots + P_n}{n}$$

If the fission products are only a few hours old and if the march movement lasts somewhat longer, then formula 7.48 will give us dose values which will be too high because it does not allow for the decay of the dose rate. In these cases it is a better idea to solve the problem with the SB-1 radiation calculator, using the average dose rate $\bar{P}$ at the start of the march movement.

One last method of dose calculation for march routes finally consists in calculating the total dose from the partial doses for individual sectors of a contaminated march route in case of differing density of measurement points and widely differing dose rates. This method is above all suitable when we have $t_a \gg t_b - t_a$; that is to say, when a longer interval of time has already elapsed since the formation of the trace. It is however very time-consuming and therefore not universally usable.

This kind of computation has the following form:

$$D = f_0 \cdot \Sigma \frac{P_{x\,km} + P_{y\,km}}{2} \Delta t \quad R \qquad (7.49)$$

that is to say, the dose calculation for the particular segment of the march route is based on the average dose rate of this segment and the time it takes to pass through this segment. The danger of external radiation is confined not only to the time interval involved in the immediate stay in contaminated terrain itself but also continues to exist beyond the radioactive contamination of combat vehicles and combat equipment after the contaminated areas have been left. Just how high the nuclear radiation doses are, to which vehicle and gun crew members will be exposed, depends on very many factors.

In case of dry ground (dust formation), the entire combat vehicle is contaminated more or less uniformly heavily whereas in case of a damp soil, contamination in fact is confined to those parts which are directly in contact with the contaminated soil. Here we get such a concentration of radioactive dirt in the suspension and along the bottom of the hull especially in the case of tracked vehicles that the resultant surface radioactivity can therefore by a multiple exceed that of the surrounding terrain. Contamination of course decreases during a subsequent march through uncontaminated terrain. Only the natural decay of fission products is responsible for this reduction in case of dry weather; in case of damp soil, the exchange of the adhering dirt masses also has a certain effect. In general we can therefore figure that the additional radiation exposure to the personnel--caused by contaminated combat vehicles--can be 10-30 percent of the nuclear radiation dose in the terrain. This is why it is not correct to explain the need for rapid decontamination only in the light of the existing danger of incorporation.

It was pointed out earlier that it is necessary in some cases, in connection with outside radiation, also to consider the effect of beta radiation. If the radioactive detonation products are found only in the terrain or on the surface of combat vehicles, etc., then the practical radius of the contaminated surface area, from which beta radiation is radiated, will be about 3-5 m. If we furthermore start with the characteristic of fission product beta radiation given in Section 7.1, then it follows that, if the troops are stationed out in the open, the resultant dose will not exceed 5-10 percent of the corresponding gamma radiation dose and that it can therefore be neglected.[57] Beta radiation is of no concern anyway when the troops are in shelters (see Section 7.1.4.2).

Another viewpoint emerges in the presence of contact radiation, that is to say, when beta-active substances get directly on the skin and especially the mucosae. In this case, all beta particles with an energy of E_β/60 to 70 keV --which penetrate the outermost skin layer (surface mass about 7 mg/cm^{-2})-- will contribute to a corresponding tissue dose. The magnitude of this dose decreases continually in case of direct contact of radioactive substances with the body surface.

Petrov[58] points out that, if the radioactive detonation products remain on the skin surface for a longer period of time, the developing high surface doses can cause serious injuries that have the character of beta burns. Such beta burns were observed for example among the inhabitants of the Marshall Islands as a result of the American nuclear weapon experiments conducted in March 1954. In case of a whole-body gamma radiation dose of about 175 rad (175 R), caused by external radiation, in case of unprotected body parts, resulting from beta radiation and soft gamma radiation, there were skin doses on the order of magnitude of 2,000 rad on the level of the heels, 600 rad on the level of the thigh, and 300 rad on the level of the head. On this basis, Petrov arrives at the conclusion that, under the conditions of heavily contaminated areas, the contact doses of beta radiation for unprotected skin can be more than 10 times higher than the whole-body doses.

This points up the great significance of wearing protective gear during operations in contaminated zones.

Table 7.19. Permissible Radioactive Contamination of Surfaces and Objects

	3 Bezeichnung	4 zulässige Aktivierung Beta-Zerfalle auf 1 cm² und min		mR/h	
		5 alt[1])	6 neu[1])	5 alt	6 neu[2])
7	Körperoberfläche des Menschen	0,05	1,1	0,75	15
8	Handflächen	0,1	2,2	0,2	4,5
9	Körperoberfläche von Tieren	0,2	2,2	3,0	30
10	Schutzmaskenhaube	0,5	1,1	1,0	10
11	Unterbekleidung	0,05	1,1	0,75	15
12	Oberbekleidung, Ausrüstung, Schuhwerk und persönliche Schutzausrüstung	0,2	2,2	3,0	30
13	Handfeuerwaffen	0,5	2,2	3,0	15
14	Bewaffnung und Ausrüstung	0,5	4,4	20,0	180
15	Oberflächen von Brunnen	0,05	1,1	2,0	45
16	Innenflächen von Anlagen	0,1	2,2	4,0	90
17	Außenflächen von Anlagen	0,5	11,0	20,0	450
18	Küchen- und Bäckerei-ausrüstungen	0,005	0,005	0,2	0,2
19	Oberflächen von Lebensmittelverpackungen	0,01	0,01	0,2	0,2

Key: (1) Figures given in millions; (2) Standards take effect in response to special instructions; 3--Item; 4--Permissible contamination, beta decays per 1 cm^2 and min; 5--Old; 6--New; 7--Human body surface; 8--Palms; 9--Animal body surface; 10--Mask hood; 11--Underwear; 12--Outerwear, gear, shoes, and personal protective gear; 13--Hand-fired weapons; 14--Armament and equipment; 15--Surfaces of wells; 16--Inside surfaces of installations; 17--Outside surfaces of installations; 18--Kitchen and bakery equipment; 19--Surfaces of food packages.

To estimate the energy dose of beta radiation, Kodochigov[59] gives the following relation:

$$D_\beta = \frac{5{,}8 \cdot 10^{-5} \cdot N_\beta \cdot E_\beta \cdot t}{\Delta} \text{ rad} \qquad (7.50)$$

N_β--Beta particle flow, cm^{-2}/sec^{-1}
E_β--Maximum energy of developing beta spectrum, MeV
t_β--Irradiation duration, hr
Δ--Whole-value layer of absorption of beta particles of given energy, g/cm^{-2}.

In view of the small dependence of the maximum permissible flux of beta particles on the energy of the prevailing spectrum in the range of up to about 10 MeV, Kodochigov points out that one may therefore consider it permissible, in determining the justifiable surface radioactivities, to start from mean values without considering specific beta energies.

Table 7.19 presents reference values for the maximum permissible surface radioactivities of some important objects. It must be kept in mind that these values must be considered not only from the viewpoint of contact radiation but also from the angle of incorporation danger. Besides, Langhans correctly points out that this table is based on very few reliable initial data.[60]

The problem complex of nuclear radiation monitoring with the help of gamma radiation measurements is explained in detail in the book by Langhans, entitled "Kernwaffenradiometrie und Kernwaffendetonometrie," DMV, Berlin, 1970, PP 87 ff.

7.4.2.2. Protection against Incorporation

If the units are properly equipped and trained, the danger of radiation damage due to incorporation of radioactive detonation products, compared to the radiation exposure caused by external radiation, recedes rather far. Nevertheless, this aspect of the direct effect of radioactive substances on the human organism must also be given a certain amount of attention. By the incorporation of radioactive detonation products we mean their penetration (incorporation) into the organism. Specifically, radionuclides can be absorbed by the body via the respiratory tract (inhalation), the digestive tract (ingestion), and through wounds (inoculation). The size of the radioactive particles, the solubility of the existing chemical compounds, and the condition of the organism during the absorption time interval itself have an effect on the process of incorporation.

In case of unit operations in contaminated areas, the incorporation of radioactive substances with the breathing air represents the greatest danger. In general, one can however expect that the lungs in case of resorption play a considerably smaller role than the digestive system. This is due to the fact that particles with a diameter of $d > 10$ µm in fact are completely filtered out, those with $d > 5$ µm at any rate are still filtered out to the extent of 95 percent in the nose and throat region, that is to say, they are filtered out of the respiration air and they are then swallowed. Particles with $2\ \mu m < d < 5\ \mu m$ on the other hand on the average get into the lungs with the flow of air to the extent of about 20 percent and those with $d < 1$ µm to the extent of about 90 percent. But particles in this order of magnitude account for only a very tiny fraction of the total radioactivity (see Section 7.2.2.1.1).

In addition to swallowing inhaled dust particles, there is another possibility for the penetration of radioactive detonation products via the digestive tract during the consumption of contaminated rations and contaminated water. This absorption of radioactive substances particularly depends on the solubility of incorporated dust particles. Such elements as uranium and plutonium

form difficult to dissolve oxides, while strontium and barium form easily soluble oxides. Radionuclides, which are trapped in larger particles with a melted surface, as a rule are not resorbed but instead are again eliminated in an undigested [undecomposed] fashion.

Wounds constitute another gateway for incorporation. Here, it is especially large and deep wounds as well as wounds caused by large-area burns that constitute a serious threat. Penetration of radioactive substances via the intact skin is also basically possible but need not be covered in the context taken up here.

The radiation exposure of the organism, caused by the incorporation of radioactive detonation products, depends on the absorbed total dose (the cumulative radioactivity), the type of radiation, the energy of radiation emitted, and the particular absorbed share, the organ distribution, and the physical and biological half-life.

Table 7.20. Rough Connection between Incorporated Total Activity of Fission Products and Resultant Degree of Radiation Sickness[61]

Degree of radiation sickness	Incorporation, mCi/kg body weight	
	Absorption through inhalation	Absorption per os
I	0.05	0.1--0.5
II	0.1	1
III	0.3	2 ... 3
LD_{100}	0.5	5

Because radioactive detonation products and the nuclear radiation emitted by them have already been described in detail, it is not necessary here once again to go into all of these factors. Table 7.20 presents some reference values for fission products concerning the degree of anticipated damage as a function of the incorporated total radioactivity.

In contrast to external radiation, incorporation naturally involves some special aspects of the radiation effect. They are based above all on the nearby location of the incorporated radiation sources with relation to some particularly radiation-sensitive cellular tissues, the high local intensity of radiation, and the differing degree of chemical affinity of the various radionuclides with the most important biogenic elements in the organism. Under combat conditions, quite generally, the maximum permissible quantity of detonation products that can be incorporated is considered to be that quantity of which the organism due to beta and gamma radiation receives no more than 0.05 rad and due to alpha radiation no more than 0.005 rad per day. Without going into any further details here, it emerges quite clearly in this context with the data in Table 7.20 what role the age of incorporated radionuclides plays in such considerations.

The incorporated radionuclides become internal radiation sources only if they get into the blood circulation system, if they are transported from there into the tissues and organs, and if they are deposited there.

(In general, the deposit of the various radionuclides in the whole body or in specific tissues and organs, after their resorption, is completed within a few hours.)

We can in a greatly simplifed manner arrange the radionuclides in three groups according to their distribution in the organism. We have those which:

Are deposited primarily in the skeleton, that is to say, in the bones, such as strontium, barium, calcium, thorium, uranium, and plutonium;

Are enriched mostly in the liver, the kidney, and the spleen, etc., such as lanthanum, cerium, polonium, and manganese;

Are distributed over individual organs without characteristic accumulation.

In this connection it must however be observed by way of restriction that, when it comes to organ distribution, the structure of the particular chemical compound, in which the corresponding radionuclide is present, is also significant. Independently of that, one can define certain "critical organs" for radioactive detonation products, that is to say, organs whose damage as a result of internal radiation will signify the greatest damage for the body as a whole.

According to Kutzim, the particular critical organ is determined in the light of the following factors:

"It must:

"(a) Reveal the highest concentration of radioactive material in the body;

"(b) It must be of special significance to the organism as a whole in functional respects among the organs considered;

"(c) The differing biological radiation sensitivity of the individual organs;

"(d) Organ damage, caused by the entry of the radionuclide into the body, must also be considered."[62]

If, in an organ, the mass M of share p of a "radioactivity quantity" A is stored, then the organ, according to Franco[63] will contain $U = p \cdot A$ radioactivity units and, considering the effective half-life, we accordingly get the following integral tissue dose (energy dose):

$$D = 1{,}6 \cdot 10^4 \frac{U \cdot T_{eff}}{M} \text{ rad} \qquad (7.51)$$

According to Frost, the equation given applies preferably to beta emitters while, in the case of complex emission spectrums, the gamma component must be considered percentage wise.[64]

Looking at the magnitude of the radiation damage caused by incorporated radionuclides, the physical half-life as well as the biological half-life are of significance. It characterizes the average time the particular radionuclide spends in a certain organ or in the body as a whole; that is to say, the time during which half of the incorporated total quantity is again eliminated.

The connection between effective, physical, and biological half-life is given by the following relation:

$$\frac{1}{T_{eff}} = \frac{1}{T_{phy}} + \frac{1}{T_{biol}}$$

or:

$$T_{eff} = \frac{T_{phy} \cdot T_{biol}}{T_{phy} + T_{biol}} \qquad (7.52)$$

Corresponding data for the individual radionuclides of detonation products can be found in tables 7.3, 7.9, and 7.10. In addition to the values for the critical organs, we also have the mean values for the whole body here.

The speed of elimination of incorporated radionuclides depends on many factors. Those radioactive substances which form easily soluble salts are eliminated most quickly whereas those which enter into complex compounds with albumins are eliminated more slowly; radionuclides deposited in or on the skeleton spend the longest time in the body. Elimination itself takes place primarily through the stool and the urine.

According to data by Vogler, the ratio of elimination in case of oral intake (digestive tract) is 9:1.[65] The course of radiation sickness caused by the incorporation of radioactive detonation products differs quite essentially from the one described in Section 5.3.3.2 regarding external radiation (instantaneous nuclear radiation). But because pure incorporation in fact is ruled out under field conditions and because we need not expect any acute radiation damage--that is to say, radiation damage leading to combat disablement--we cannot go into any greater detail here regarding the problem complex of possible delayed damage. We will not make any further statements here.

Protecting units against the danger of incorporation during operations in contaminated zones can in particular be guaranteed by the following:

Timely use of personal protective gear and use of combat vehicles and permanent shelters equipped with filter ventilation systems;

Correct behavior in contaminated terrain;

Compliance with strict ration and water supply schedules and procedures;

Timely implementation of decontamination and medical treatment measures; and

First-aid measures as well as specific therapy for radiation victims by the Medical Corps.

The foundation for this overall complex of protective measures consists of uninterrupted conduct of nuclear radiation monitoring and the goal-oriented analysis of the nuclear radiation situation.

Table 7.21 is a compilation of the most important protective measures and rules of behavior during operations in contaminated terrain.[66]

We can see that putting on the protective mask in moist weather is not absolutely necessary.

Rations for the troops must be protected against indirect contamination by radioactive dust with particularly great care. Basically, this involves simple measures to prevent "radioactive contamination" of essential and non-essential foods during processing, transportation, preparation, and consumption which however are difficult to implement in practice. To understand the complete content of this, one must get away from any preconceived notions to the effect that visible quantities of radioactive dust must be present and that they are the ones which lead to incorporation with dangerous consequences. The exact opposite is the case. For example, theoretically, 1 g of radioactive fission products can lead to the most severe radiation damage in 50,000 people.

Proper packaging is of great importance.

Essential foods, present in cans or in repeatedly sealed plastic pouches, are reliably protected against contamination due to radioactive dust. They can be consumed without worry after careful decontamination of the packaging, regardless of how high the previous surface radioactivity of the package was.

The preparation of ration products and meals in contaminated terrain is complicated inasmuch as there is always a danger here that radioactive detonation products might also be processed along with the food. This danger can be countered effectively by means of careful selection of stationing areas for ration supply services (field bakeries, slaughter sections, kitchen facilities, field kitchens, etc.), preparation of meals under the most hermetical circumstances possible or other fixed installations, partial terrain decontamination or wetting the ground and constant nuclear radiation monitoring. The essential prerequisites for the success of such measures include the fact that all army personnel must fully understand their content and that these measures must be implemented in a disciplined fashion and that the standards and characteristic values in the corresponding service regulations must be strictly complied with.

Table 7.21. Important Protective Measures and Rules of Behavior during Operations in Contaminated Terrain

Protective gear to be used		Rules of behavior and protective measures
In case of dusty air (dry, windy weather, snow-storm)	In case of clean air (moist weather, after rainfall or snowfall)	
Crossing contaminated sectors on foot		
Individual protective gear	Protective stockings, cape and gloves	Speed up march tempo, avoid dust formation, do not touch contaminated objects, bypass sectors with high dose rates
Crossing contaminated sectors mounted on motor vehicles, APC's, and tanks		
Individual protective gear	Protective stockings, cape and gloves	Increase march movement speed, increase intervals, do not touch contaminated objects when dismounting
Crossing contaminated sectors in tanks and closed APC's (without filter ventilation system)		
Mask		Close hatches and shutters, turn fans off
Staying in contaminated terrain		
Mask, protective stockings and gloves	Protective stockings and gloves	Use shelter facilities improved by Engineers and others, avoid staying in sectors with high dose rates, improve shelter facilities, decontaminate, organize meal times and rest in shelters, units operating in sectors with high dose rates must periodically be relieved.

To guarantee the water supply, especially drinking water, we must among other things make full use of the water filtering stations available on the individual echelons; by means of their ion exchanger systems, they guarantee complete decontamination of the water while complying with the prescribed operating rules. It is furthermore possible to cover smaller open watering places or wells and thus to prevent contamination by radioactive dust at the right time. Larger quantities of water must above all be taken from deep wells because natural decontamination takes place in the soil. Constant nuclear radiation monitoring is necessary here likewise. Furthermore, water consumption must be reduced to a minimum. Even lightly contaminated surface water--possibly from flowing water bodies--can be used as utility water, for example, for decontamination.

Because the questions of decontamination and medical treatment are covered in a summarized fashion in Section 7.4.4, we will not go into any further detail here. It must however be observed that one must not view decontamination only from the viewpoint of preventing the incorporation of radioactive substances or additional radiation exposure. Instead, one must keep in mind that wearing protective gear is not possible to an unlimited degree and that this leads to extraordinarily heavy physical and psychological stresses on fightingmen above all when outside temperatures are higher. This can cause a considerable reduction in combat capacity.

Table 7.22 supplements Table 7.19 and contains some important maximum permissible radioactivities for various foodstuffs and other products.[67]

Table 7.22 Important Maximum Permissible Radioactivities for Nuclear Radiation Monitoring of Essential Foods, Fodder, Liquids, and Air (MzA)

Meßobjekt	β-Zerfallsprozesse je min und je				α-Zerfallsprozesse je min und je			
1 2	cm^2	cm^3	g	l	3 cm^2	cm^3	g	l
4 Nahrungsmittel und Gewürze bei nur eintägiger Aufnahme	$5 \cdot 10^3$	$5 \cdot 10^4$	–	–	$5 \cdot 10^2$	$5 \cdot 10^3$	–	–
5 Nahrungsmittel und Gewürze bei einer 5tägigen Aufnahme	10^3	10^4	–	–	10^2	10^3	–	–
6 Futtermittel für einige Tage	$5 \cdot 10^3$	$5 \cdot 10^4$	–	–	$5 \cdot 10^2$	$5 \cdot 10^3$	–	–
7 Trinkflüssigkeit bis zu 2 l	–	$5 \cdot 10^4$	$5 \cdot 10^4$	$5 \cdot 10^7$	–	$5 \cdot 10^3$	$5 \cdot 10^3$	$5 \cdot 10^6$
8 Trinkflüssigkeit bis zu 10tägiger Aufnahme	–	$5 \cdot 10^3$	$5 \cdot 10^3$	$5 \cdot 10^6$	–	$5 \cdot 10^2$	$5 \cdot 10^2$	$5 \cdot 10^5$
9 Brauchwasser (Brauchflüssigkeit)	–	$2 \cdot 10^5$	$2 \cdot 10^5$	$2 \cdot 10^8$	–	$2 \cdot 10^4$	$2 \cdot 10^4$	$2 \cdot 10^7$
10 Atemluft bis zu 1stündiger Aufnahme	–	10^2	–	10^5	–	10	–	10^3
11 Atemluft bis zu 10stündiger Aufnahme	–	10	–	10^4	–	1	–	10^2

Key: 1--Object to be measured; 2--Beta-decay processes per minute and per; 3--alpha-decay processes per minute and per; 4--Essential foods and seasonings for only one-day consumption; 5--Essential foods and seasonings for 5-day consumption; 6--Fodder for several days; 7--Drinking liquid up to 2 lit; 8--Drinking liquid up to 10-day consumption; 9--Utility water (utility liquid); 10--Respiration air up to 1-hour absorption; 11--Respiration air up to 10-hour absorption.

7.47. What are the basic principles we must use in calculating the anticipated dose absorption by the troops? How accurate are such computations?

7.48. What is the significance of possible incorporation of radioactive substances?

7.49. With the help of some practical examples, explain the most important measures for protecting units against incorporation.

7.50. What is the essential content of behavior rules during operations in contaminated terrain?

7.51. What are the maximum permissible radioactivities and how must we work with these values?

7.52. What is the mission of nuclear radiation reconnaissance? Explain the forms of nuclear radiation reconnaissance.

7.53. Compile the performance possibilities and typical operational variants of nuclear radiation reconnaissance on foot, with combat vehicles, and with helicopters. Compare the advantages and disadvantages in each case.

7.54. What types of reports on terrain contamination can be forwarded from the reconnaissance agencies to the staffs and between the staffs?

7.55. Explain the content and organization of dosimetry. (Note that the nuclear radiation doses from instantaneous nuclear radiation must also be recorded.)

7.56. Why is it wrong to believe that the difference between partial and complete special treatment (decontamination) boils down to whether support is or is not given by chemical defense units?

7.57. What methods can be used for decontamination and medical treatment? Explain them with the help of some examples.

7.5. Footnotes for Chapter 7

1. These questions are presented in a continuing manner in Section 7.4.1.

2. We used the following values in compiling the data in Table 7.1:

   Radioactivity of Pu-239: 60 Ci kg^{-1}
   Radioactivity of U-238: $3 \cdot 10^{-4}$ Ci kg^{-1}
   Radioactivity of Fission Products: $2 \cdot 10^{12}$ Ci kg^{-1}
   Efficiency of nuclear fission of Pu-239: $\eta = 20\%$
   Efficiency of nuclear fission of U-238: $\eta = 15\%$.

3. More detailed data on the fission products developing from the fission of various nuclear explosives due to neutrons of differing energy can be found among others in Katcoff, S., Nucleonics 18 (1960) 11, pp 201 ff.

4. The table was taken over unaltered from Lavrenchik, V. N., "Global'noye vypadeniye produktov yadernykh vrtsyvov," Atomizdat, Moscow, 1965, p 12 f. (This work also contains a compilation of Soviet and American original studies on this topic complex.)

5. Ibid., p 8.

6. The picture was copied in a simplified manner from Strauss, H., "On the Determination of Maximum Permissible Concentrations of Radioactive Fission Products in Drinking Water for Disaster Cases," SZS Report, 3, 1967, p 15.

7. Additional statistics can be found among others in Leipunskiy, O. I., "Gamma Radiation from Nuclear Weapon Detonations," Moscow, 1959, Russian; Langhans, K., "Kernwaffenradiometrie und Kernwaffendetonometrie," German Military Publishing House, Berlin, 1970; Zakutinskiy, D. I., and others, "Spravochnik po radioaktivnykh izotopov," Moscow, 1962.

8. Way, K., and E. Wigner, Phys. rev. 73 (1948) p 1318.

9. Levochkin, F. N., and Yu. Ya. Sokolov, Atomnaya energiya, 10, 1961, p 403.

10. Petrov, R. V., and others, "Zashchita ot radioaktivnykh osadkov," Medgiz, Moscow, 1963, p 166.

11. The values in the table were partly taken from Petrov, loc. cit., p 167.

12. The picture was taken from Lavrenchik, V. N., "Global'noye vypadeniye...," loc. cit., p 15.

13. In the literature reviewed, data for the average energy of beta and gamma radiation vary up to 25 percent from the figures given in Table 7.5. We cannot go into any greater detail here regarding the reasons for this. It may merely be noted that the gaseous detonation products were not included in the computations.

14. Spencer, L. V., "Structure shielding against fallout radiation from nuclear weapons," Washington, National Bureau of Standards, Monograph 42, June, 1962, Russian edition from Atomizdat Publishing House, Moscow, 1965, p 14.

15. Bjoernerstedt, R., Arkiv foer Fysik 16 (1959) 28, pp 293 ff.

16. For comprehensive information on the term of the effectiveness [action] cross-section used here, reference is made to "Kleine Enzyklopaedie Atom, Struktur der Materie" [Small Encyclopedia, Atom, Structure of Matter], VEB Bibliographic Institute, Leipzig, 1970, pp 150 ff. In a greatly simplified manner we might say this: The action cross-section is a measure of the yield of a nuclear reaction. As the probability of the materialization of a certain reaction, it is made up of the penetration probability (in the special case of neutrons) and the conversion probability. For illustration purposes we can assume that

an atomic nucleus, bombarded with certain particles, will oppose the flow of projectiles with a certain cross-section. As a unit of measure for this action or effectiveness cross-section we use the surface area of 10^{-28} m which roughly corresponds to the geometric cross-section of heavy nuclei and we label it as 1 barn.

17. On this problem complex, see also Yampol'skiy, P. A., "Neytrony atomnogo vtsryva," Gosatomizdat, Moscow, 1961, Chapter 2.

18. Lavrenchik, V. N., "Global'noye vypadeniye...," loc. cit., pp 18, 19.

19. Ibid., pp 21-23.

20. Ibid., p 23.

21. The table was compiled with the help of data from Langhans, K., "Kernwaffenradiometrie ...," loc. cit., p 58, and DV-66/3, MfNV 1963, pp 366.

22. See also DV- 66/3, loc. cit., p 366 ff.

23. The Plowshare Program, Appl. Atomics (1962) 4, p 353.

24. Nifontov, B. I., and others, "Podzemnye Yadernye vtsryvy," Atomizdat, Moscow, 1965, pp 80 ff.

25. See also Langhans, K., "Kernwaffenradiometrie...," loc. cit., p 35.

26. Other necessary numerical data for computations to be made can be found among others in the following works: "Kleine Enzyklopaedie Atom, Struktur der Materie," VEB Bibliographic Institute, Leipzig, 1970; Haissinsky, M., and J.-P. Adloff, "Principal Characteristics and Applications of the Elements and their Isotopes," New York, 1965, Russian edition from Atomizdat Publishing House, 1968; Gordeyev, I. V., and others, "Yaderno-fizicheskiye konstanti," Gosatomizdat, 1963.

27. Gusev, N. G., "Leitfaden fuer Radioaktivitaet und Strahlenschutz," [Guide for Radioactivity and Radiation Protection], VEB Technical Publishing House, Berlin, 1957, p 80.

28. Langhans, K., "Kernwaffenradiometrie...," loc. cit.

29. Gosev, N. G., "Leitfaden fuer Radioaktivitaet ...," loc. cit., p 81.

30. On this problem complex, see also Christofilos, N. C., "The Argus Experiment," J. Geophys. Res. (1959), pp 1699 ff.

31. In addition to special military models, this among other things involves models of atmospheric mixing and circulation and exchange models. In this connection see also Machta, L., and others, A Survey of Radioactive Fallout from Nuclear Tests, J. Geophys. Res. 67 (1962), p 1389;

Staley, D. O., On the Mechanism of Mass and Radioactivity Transport from Stratosphere to Troposphere, J. Atm. Sci 19 (1962), p 450; Libby, W. F., Moratorium Fallout and Stratospheric Storage, J. Geophys. Res. 68 (1969) p 2933 and p 6215; Lavrenchik, V. N., "Global'noye vypadneniye ...," loc. cit., Fuchs, S., "Mathematical Methods for the Approximate Determination of Terrain Contamination and the Resultant Conclusions for the Commander," dissertation, The Friedrich Engels Military Academy, 1964.

32. Problems connected with detonations in the ionosphere and outer space are not considered in the following presentations.

33. See also Lavrenchik, V. N., "Global'noye vypadeniye ...," loc. cit., p 147; Langham, W., and E. C. Anderson, "Fallout from Nuclear Weapons Tests Hearings 1959," US Govern. Print. Office, Washington, 1959, p 1068.

34. The picture was taken from Budzhko, V., T. Bukalskiy, "Meteorologichne problemy prognozovaniya skazen," Mysl Woyskova, 1964, 4, p 54.

35. Ibid., p 55. (The picture was redrawn.)

36. The Wahnsdorf Meteorological Observatory was kind enough to make the picture available for which we want to express our appreciation. See also Zier, M., "On the Global Transport of Fission Products of Past Nuclear Weapon Tests in the Atmosphere and Their Appearance in the GDR," MILITAERWESEN, 1965, 5, p 685.

37. On this problem complex see Kusin, P., "Ten Million Victims in One Generation," PROBLEME DES FRIEDENS UND DES SOZIALISMUS [Problems of Peace and Socialism], 1959, 9, pp 51 ff.

38. Zier, M., "On the Global Transport ...," loc. cit., p 685 f.

39. See also Fuchs, S., "Mathematical-Physical Considerations on Terrain Contamination after Nuclear Weapon Explosions," MILITAERWESEN, 1954, 11, p 1602.

40. The picture was changed and was taken from Timofeyev, B. N., and Yu. K. Nesytov, "Prognozirovaniye radioaktivnogo zarazheniya," Publishing House of the USSR Defense Ministry, Moscow 1969, p 12.

41. Ibid., p 14. (The type of illustration was altered.)

42. The conversion of these values for other times after detonation will be explained in Section 7.3.

43. On this problem complex, see Boehme, F., and K. Mendel, "On the New Method of Analytical Evaluation of Nuclear Weapon Strikes," MILITAERWESSEN, 1966, 7, pp 990 ff.

44. The picture was taken from Nifontov, B. I., and others, "Podzemnye ...," loc. cit, p 71.

45. Ibid., p 84.

46. The treatment of this problem complex is impossible without a major mathematical effort. If necessary, this section can be skipped, except for the conclusions given.

47. Fuchs, S., "Mathematical Methods for the Approximate Determination of Terrain Contamination and the Resultant Conclusions for the Commander," dissertation, "Friedrich Engels" Military Academy, 1964, pp 113-116.

48. Spenser, L. V., "Structure shielding ...," loc. cit., pp 39 ff.

49. The values of this function among others are given in Jahnke-Emde, "Tafeln hoeherer Funktionen" [Tables of Higher Functions], B. G. Teubner Publishing Company, Leipzig, 1952, 5th edition, p 1 and pp 6-9.

50. In general we can say that, if we include multiple scatter in the calculations, we get dose rate values which are about 25-50 percent higher than shown in Formula 7.29. Because of the uncertainty of the initial values, this however plays only a subordinate role in many cases in rough estimates.

51. The k-values can be taken from the pertinent service regulations.

52. In Table 34 of DV-36/2, the distribution of the integral nuclear radiation dose is not related to 1 hour after detonation but rather to the "duration of nuclear radiation from the moment of radioactive trace formation on." Because of that, the values given differ somewhat from each other.

53. On this problem complex, see Rudloff, A., "Determination of Dose Rate and Dose in Case of Superposition of Fallout Fields from Several Detonations," "Zivilschutz," 1962,2, pp 60-64.

54. The term "analytical evaluation" is used here in the sense of theoretical advanced calculations on the basis of the results of nuclear weapon detonations with the help of tabulated fallout models, etc.

55. This subdivision into "technical" and "semistrategic-tactical" measures of protection activities is by no means intended to create a formal dividing line. It is however practical for methodological reasons and permits clear statements.

56. DV-36/2, p 40.

57. That such a statement can be made emerges from the fact that the measurement errors for gamma radiation are considerably higher.

58. Petrov, R. V., and others, "Zashchita ot radioaktivnykh osadkov," loc. cit., pp 70 ff.

59. Kodochigov, P. N., "Oprakticheskikh voprosakh dozimetrii ioniziruyushchikh izlucheniy," Izdatel'stvo akademii nauk SSSR, Moscow, 1962, p 30.

60. The table was taken from DV 053/0/003.

61. The table was taken from special reprint "Radiation Damage" by the Military-Medical Information and Documentation Office, Ernst Moritz Arndt University, Greifswald, 1967, p 5.

62. Quoted from Kutzim, H., ATOMKERNENERGIE, 7, 1962, 12, p 487.

63. Franco, V. H., and others, Medical Sciences, Vol. I, Pergamon Press, Ltd., London, 1956, quoted from Frost, D., "Praktischer Strahlenschutz," Berlin, 1960, pp 11 ff.

64. Ibid., p 13.

65. On this problem complex, see Vogler, H., "Incorporation--Decorporation," Information Service of the NVA, Military Medicine Series, No 5, 1971, pp 37 ff.

66. The table was compiled on the basis of Table 22 in DV-36/2, p 26.

67. The table was taken over unaltered from Langhans, K., "Kernwaffen-radiometrie ...," loc. cit., p 87.

68. On this problem complex, see DV-36/1, pp 25 ff.

69. See also Langhans, K., "Kernwaffenradiometrie ...," loc. cit., pp 72 ff.

70. On this problem complex, see Hoffmann, M., "On Radiation Reconnaissance Using Helicopters," MILITAERWESEN, 1962, 5, pp 713 ff.

71. Petrov, I. G., "Dezaktivatsiya, degazatsiya i dezinfektsiya, Zhurnal vsesoyuznogo Khimicheskogo obshchestva, 18, 1968, 6, pp 699-703.

72. Blumenstein, W., "Entigftungs- und Entaktivierungsgeraete" [Chemical and Radiological Decontamination Instruments], German Military Publishing House, Berlin, 1965, 225 p.

8. Nuclear Weapon Protection as Integral Component of Unit Protection against Mass Annihilation Weapons

8.1. Summary of Most Important Measures of Unit Nuclear Weapon Protection

In the introduction to this textbook we already observed that unit nuclear protection is an integral component of unit protection against mass annihilation weapons and must in all combat types and in every situation be organized with the goal of preventing the use of mass annihilation weapons to the maximum extent, reducing the effects of enemy attacks, preserving or rapidly restoring the combat value and combat readiness of units, and to guarantee the accomplishment of the combat mission.

This objective means that we can have protection of units against mass annihilation weapons only if it is a properly planned, organized, and implemented task and if it is made the content of the work of all commanders and staffs as well as all arms of the service, special units, and supporting units, even if the enemy has not yet used any mass annihilation weapons.

The constant guarantee of unit protection against mass annihilation means is a most profoundly creative task which calls for in-depth evaluation of the situation and decision-making full of initiative and without any stereotype approach.

The partly still existing practice of subdividing measures for the protection of units against mass annihilation weapons into so-called active and passive measures is at least impractical because it no longer does justice to the significance of the individual measure and above all because it gives a false basic orientation.

Table 8.1 summarizes once again and clearly presents the most important measures of unit nuclear weapon protection. But because these measures have already been explained in detail in the past chapters, we need not make any further statements here.[1]

The prerequisites and foundations for constant and all around implementation of protection against mass annihilation weapons in combat must be created today to the fullest extent in the training of commanders, staffs, and units. This in particular makes it necessary to have a clear concept as to the essence and effect of mass annihilation weapons, to be convinced as to the necessity and possibility of protection, and to develop in depth and train the theoretical and practical knowledge and skills absolutely necessary for this. Here, the conviction as to the victorious nature and the defense worthiness of socialism, combined with courage, steadfastness, and the readiness to sacrifice, will play a decisive role.

The external conditions and phenomena of a nuclear missile war lead to extraordinarily heavy psychological-moral and physical stresses on commanders, staffs, and troops. They are caused by the simultaneous action of a large number of influencing factors. They include sudden and crass changes in the situation as a result of enemy attacks with mass annihilation weapons, the appearance of mass casualties, the forced stay in areas with high dose rates, the need for rapid decision-making even when there is no big picture as to the developing situation, repeated and long-lasting operations while wearing protective gear and many others among the problems covered in the preceding chapters.

Table 8.1. Compilation of the Most Important Measures for Unit Nuclear Weapon Protection

Measures	Content of Measures
Timely reconnaissance of enemy preparations for the employment of mass annihilation weapons and prevention of employment of these weapons	Coordinated, uninterrupted employment of all reconnaissance agencies of the arms of the service, special units, and supporting units; Reconnaissance of the deployment, movement, and firing positions of nuclear weapons, nuclear weapon depots, places for the preparation of nuclear charges, etc.; Immediate destruction of such observed objects by using all available means, such as the rocket forces and artillery, the air forces, special reconnaissance and demolition teams raders.
Advance determination of contaminated areas as well as specific indication of areas in which we find comprehensive destruction, fires, or floods resulting from nuclear weapon employment	Evaluation of enemy's specific possibilities for the employment of nuclear weapons on the basis of the existing situation (nuclear weapons, ranges, detonation intensities, detonation types, targets); Possibilities for the employment of ground and underground bursts in particular (character of operations, high-altitude weather situation, areas for laying nuclear mines, anticipated nuclear radiation situation); Evaluation of particularly endangered directions and areas (cities, woods, dams, lakes regions, impassable terrain sectors, introduction and deployment sectors for the second echelons and reserves, forced-crossing sectors, etc.); Consideration of conclusions deriving from situation estimated for decision-making and assignments to units; Forward-looking analysis of the effects of enemy nuclear strikes on the accomplishment of missions and scope of measures to eliminate consequences;

Measures	Content of Measures
Permanent organization and conduct of nuclear radiation reconnaissance	Uninterrupted reconnaissance of the most important areas, sectors, march routes, and directions by organic and nonorganic nuclear radiation and chemical reconnaissance groups; Determination of the points of main effort for reconnaissance, practical distribution of forces and resources, timely assignment to the reconnaissance units, guaranteeing steady command and communication; Conduct of calculations as to the probability of unit radiation exposure.
Timely warning of units and rear-area logistic support services as to decontamination	Utilization of all available communications and communications equipment; Determination of uniform signals and sequence of warning message transmission; Forward-looking analysis of propagation directions of radioactive detonation clouds; Timely transmission and analysis of reconnaissance data for nuclear radiation situation.
Decentralization and camouflage of field units and rear-echelon logistic support services	Complete utilization of available area for stationing and deployment of units; Maintenance of specified distances, intervals, and safety distances; Avoidance of impermissible unit concentrations during the introduction of second echelons and reserves, at river crossings, road junctions, etc.; Implementation of measures of camouflage, sham concentration areas, concealment of unit movements, exploitation of nighttime for regrouping, limiting time spent in areas.

Measures	Content of Measures
Change of standby areas for units, basing of air units, as well as positions of ships	Disorientation of enemy reconnaissance by means of covered stationing of units and high varied operations; Consideration of enemy's reconnaissance possibilities and timely shift of units from endangered areas; Irregular change of standby and assembly areas, unit basing, and stations;
Use of individual protected gear as well as exploitation of protective properties offered by combat vehicles, terrain, and cover [shelters]	Guarantee of high level of protective training and constant action readiness of protective gear; Use of natural protective properties of terrain for unit stationing and movement on the battlefield; Stay in combat vehicles, positions, and shelters.
Preparation of roads for maneuver and Engineer-technical improvement of areas to be occupied by units	Evaluation of possible terrain-altering effects of enemy nuclear strikes (passability of roads and trails, bridges, possible floods, fire zones, etc.); Reconnaissance of the road and trail network, implementation of repair work, strengthening the carrying capacity of bridges, placing signs on roads and trails; Improvement of positions and shelters (shelter facilites) and constant increase in their degree of protection with maximum use of natural protective properties offered by the terrain, the existing built-up areas, etc.
Practical action in contaminated areas	Strict implementation of protective measures and behavior rules while staying in radioactively contaminated terrain; Restricting the times spent in zones with high dose rates or bypassing such zones or waiting for radiation to decay before crossing them.

Measures	Content of Measures
Dosimetry and nuclear radiation monitoring	Constant advance computation of anticipated unit radiation exposure ; Regular analysis of dosimetry (measurement, records, evaluation of possible effects on combat capacity, conclusions concerning further employment) ; Dispatch of instant reports in case of high dose exposure or dispatch of daily collective reports corresponding to the determinations specified; Nuclear radiation monitoring after leaving contaminated area or after complete decontamination; Regular check on unit supplies, such as rations, water, clothing, and gear concerning existing contamination (taking samples, laboratory tests).
Hygienic and preventive measures	Prevention of incorporation of radioactive substances (ban on the use of captured rations, local resources, water from watering places not cleared, etc.); Implementation of strict ration and water supply system; Administering radiation protection substances
Timely and constant supply of units with protective gear	Determination of sequence and main efforts of supply movements; Deadlines, type and place of supply or pickup ; Staggering of unit supplies and reserves; Utilization of local resources after clearance ·
Fast elimination of consequences of enemy use of mass annihilation weapons	(This question is separately covered in Section 8.2.)

Considering the realization that unit command primarily means individual leadership and that, even in the most complicated situation, the unity of political and military leadership must be guaranteed, one may therefore view the protection of units against mass annihilation weapons not simply as a sum of individual measures, decisions, and orders but one must rather understand that this can be done only on the basis of a specific and goal-oriented political effort in combat, in a planned, organized, and effectively executed manner. Here one must not overlook the fact that the constant and direct threat to life can trigger individual reactions, such as fear and mental inhibitions, combined with physical performance decline, as well as group reactions, such as fear and panic.

Among the factors which restrict the possibility of a panic, a central position is held by the political and morale condition of the troops and the knowledge that the cause for which they are fighting is a just one. But specific knowledge as to the possible dangers and the countermeasures to be taken also play an important role.

This is why it is necessary to prepare the troops for the demands of a nuclear missile war. In this connection, impermissible simplifications are just as harmful as uncritical exaggerations.[2] We need no further explanation here to show that, if we bring out and illustrate the realistic conditions of a nuclear missile war unleashed by the imperialists, strict limits will be placed on combat training. Regardless of this, the realistic combat training and preparation of the troops assume great importance. Their implementation above all requires:

The guarantee of a high theoretical training level,

A consistent fight against simplifications and the easy way out in combat training,

The implementation of the knowledge that practice cannot be considered as a criterion by itself,

The basic principles and standards of protecting units against mass annihilation weapons must not simply be considered quantitative requirements but rather qualitative necessities,

The existing training base and time must be used to the maximum extent for realistic combat training,

Complicated initial situations must be created in all combat training, that is, situations whose mastery requires maximum psychological and physical efforts.

Only the close tie-in of political motivation of the combat mission and military skills will create the guarantee for the accomplishment of the military mission. This political and morale education last but not least calls for the collective attitude of each member of the military service, it shapes character and will qualities and guarantees the superiority of socialist soldier personalities. In this connection, resoluteness, self-control,

and the certainty of victory on the part of all superiors and the example they set in every situation are of outstanding significance because they have a stimulating effect on the actions of the subordinates. The need for psychological preparation results from the mastery of demoralizing environmental factors in combat and from the problem arising from the interrelationship between man and technology. An important goal here is to develop an active attitude, that is to say, not to allow any passively tolerating and suffering behavior. In this connection, the confidential relationship of trust between superiors and subordinates is very important. It must be so developed that the subordinate even in complicated situations will be convinced and will remain convinced that the superior is doing everything he can to win victory over the enemy, to preserve the combat readiness of units under his command, and to avoid senseless sacrifices.

These psychological aspects must be considered in the creation of the most realistic possible situations in combat training. This is why such training elements, which demand the constant overcoming of fear and anxiety, have a high educational value. This is possible, without creating really dangerous situations in combat training, if the required safety regulations and protective measures are consistently complied with and carried out and if the particular requirements correspond to the training level.

Summarizing, we can say that, to attain a high level in unit training for protection against mass annihilation weapons, the important thing is:

To use all possibilities for the political and morale permeation of training,

To develop a vast wealth of ideas in the creation or description of situations that come close to modern combat, and

Systematically to train those elements and actions which must take place rapidly and "automatically" in combat.

Review Questions

8.1. Name and explain the most important unit nuclear protection measures.

8.2. Why is nuclear weapon protection an essential component of protection against mass annihilation weapons to begin with?

8.3. With the help of Table 8.1, try to develop some main points in nuclear weapon protection for units as a function of the individual types of combat. Why is it not correct to speak of special and unusual aspects in this context?

8.4. What is the meaning of "implementation of the unity of political and military leadership" under the conditions of mass annihilation weapon employment by the enemy?

8.5. What personal conclusions did you draw from the study of the problems of nuclear weapons and nuclear weapon protection for your own work?

8.6. To what extent can and must the prerequisites for all around and successful implementation of unit protection against mass annihilation weapons be created during the training of the commanders, staffs, and troops?

8.2. Tasks of Commanders and Staffs in Preparing Situation Estimate after Enemy Nuclear Strikes and in Organizing and Implementing the Elimination of the Consequences[3]

Even after enemy nuclear weapon strikes, the primary mission of commanders and staffs is to guarantee the further accomplishment of the assigned combat mission to the maximum extent. The extent to which that is possible will of course depend on the specific effects of the particular enemy nuclear weapon strikes.

By means of thorough evaluation of the arising situation, oriented toward main points, it is necessary to create prerequisites in order to restore the combat readiness of the major and minor units involved in the shortest time possible.

The elimination of the consequences of an enemy nuclear strike specifically encompasses the following:[4]

Restoration of unit command;

Reconnaissance of areas hit;[5]

Rescue work, medical treatment, and evacuation of casualties;

Special treatment (radioactive decontamination and medical treatment);

Clearing and restoration of march routes, restoration or construction of shelters and barriers as well as extinguishing and controlling fires that hinder unit operations;

Nuclear radiation monitoring and dosimetry;

Decontamination of unit supplies, especially rations and preparation of water.

The restoration of unit command is the prerequisite and basic condition for the accomplishment of all other tasks. This among other things springs from the fact that the situation, arising after an enemy nuclear strike, as a rule will be confused and that incoming messages and information will be contradictory. Regardless of that, commanders and staffs cannot wait with their decision-making and with their assignments until they have the big picture. This is why, in such a situation, all deliberations, situation estimates, and calculations must be based on the particular most unfavorable variant as the basic variant.

Considering the combat mission assigned to the units, enemy action, the position of units at the time of the nuclear strike, the specific terrain

conditions, and weather conditions, the commanders and staffs must evaluate the probable casualties, the possible psychological effects on the directly or indirectly hit units due to shock and panic, as well as the terrain-altering effects of nuclear weapon detonations and their influence on the accomplishment of the combat mission. Just exactly how accurately this can be done will depend on the available initial data. If data on the type of detonation are not available, then one must for the time being figure on a ground burst.

Earlier we pointed out that, under certain conditions, the terrain-altering effects of nuclear weapon detonations can be very great. This includes not only large and heavily contaminated craters but also large-area fires, rubble zones, roadblocks, floods due to broken dams and obstruction of rivers, impassability of valleys, gorges, etc.

The analysis of these problems will yield not only conclusions as to the further course of combat but also on the scope and degree of complexity of rescue work to be done.

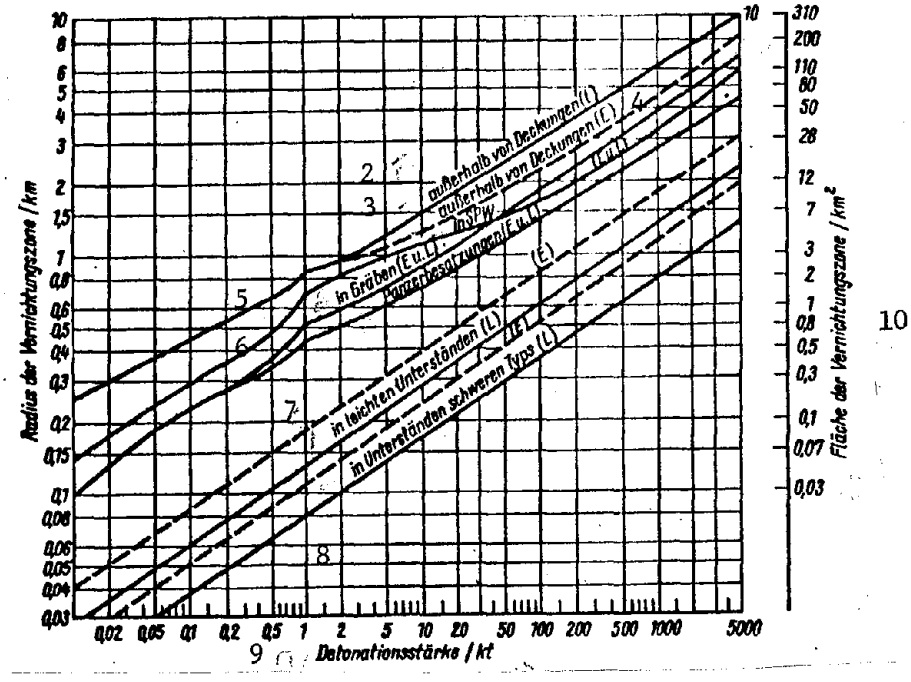


Figure 8.1. Radii of destruction zones as a function of the protection status; (L) Air burst; (E) Ground burst; if the difference in the annihilation radii are small, then both values were combined. Key: 1--Radius of annihilation zone, km; 2--Outside shelters (L); 3--Outside shelters (E); 4--In APC; 5--In trenches (E and L); 6--Tank crews (E and L); 7--In lightweight shelters (L); 8--In shelters of the heavy type (L); 9--Detonation intensity, kt; 10--Surface area of annihilation zone, km^2.

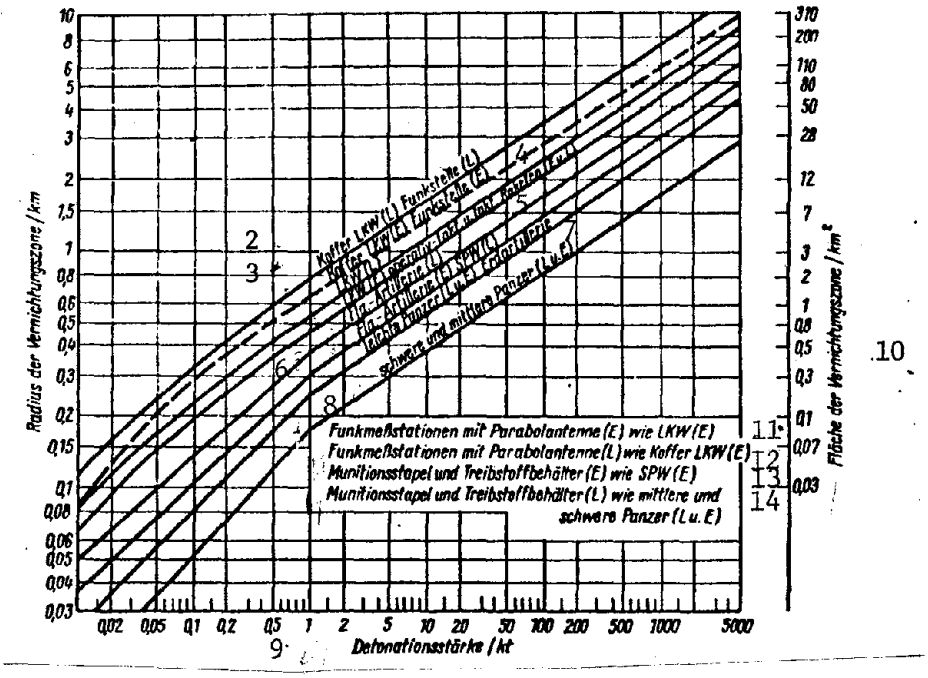


Figure 8.2. Radii of annihilation zones for combat vehicles and combat equipment. Key: 1--Radius of annihilation zone, km; 2--Truck body superstructure, (L), radio station (L); 3--Truck body, (E), radio station (E); 4--Truck (E) [illegible],semistrategic and tactical as well as tactical rockets (E and L); 5--AA artillery (L); 6--AA artillery (E), APC (L); 7--Light tanks (L and E), field artillery; 8--Heavy and medium tanks (L and E); 9--Detonation intensity, kt; 10--Surface area of annihilation zone, km^2; 11--Radar stations with parabolic antenna (E) same as truck (E); 12--Radar stations with parabolic antenna (L), same as truck body (E); 13--Ammunition stack and fuel tanks (E) same as APC (E); 14--Ammunition stack and fuel tank (L), same as medium and heavy tanks (L and E); LKW--truck.

Other difficulties arise from the fact that one must in addition figure on heavy terrain contamination.

Because of the justified assumption that the enemy will always try to make maximum use of the results of his nuclear strikes, much attention must be devoted to the rapid restoration of the fire and barrier system. In this context, increased significance must be assigned to the clearing of important march routes, the restoration of convoy routes, and other measures to guarantee freedom of maneuver, especially for the second echelons and the reserves.

Rescue work in detonation areas encompasses the following:

Searching for victims and rescuing them from combat vehicles and from destroyed or damaged installations;

Rendering first aid;

Evacuation of casualties for further medical treatment at dressing stations.

It is characteristic of the course of rescue work that, as a rule, measures involved in the removal of wreckage, fire-fighting, and clearing march routes and trails must be carried out simultaneously. In addition we have the fact that the particular degree of terrain contamination can essentially influence the course of rescue work.

The combined character of casualties, damage, and destruction resulting from nuclear weapon detonations requires the simultaneous and concentrated use of rescue and recovery detachments whose numerical strength and makeup must correspond to the particular task to be accomplished. The practical implementation of such a requirement, especially in case of massive enemy strikes, however is not always possible to the fullest extent. It is last but not least for this reason that the immediately involved major and minor units must, along with the restoration of combat readiness, organize self-aid and mutual assistance and efficiently start to eliminate the consequences of such strikes without mostly waiting for aid and support from superiors. The sooner we start with the elimination of the consequences, the less will be the anticipated secondary losses and the more quickly can the demoralizing effects be brought under control and the more effectively can we fight against anxiety and panic reactions.

There is no question that even the best-organized unit protection system against mass annihilation weapons cannot completely prevent heavy losses and casualties. But it is indeed possible to minimize the absolute level of these losses by making sure that the commanders, staffs, and troops in the field will theoretically and practically be fully prepared for the problems to be solved in combat, and for the protection of units against mass annihilation weapons.

In his speech to the personnel of the National People's Army on [the Island] of Ruegen in January 1972, First Secretary, Central Committee, Socialist Unity Party of Germany, Erich Honecker made this observation: "In the present-day world, which has been altered by the force of socialism and which keeps changing, imperialism can no longer attain its goals the way it did 30 or 50 years ago. Nevertheless, it remains aggressive, insidious, and dangerous. As the barbaric war adventures against the peoples of Vietnam, Cambodia, Laos, and in the Arab states show, the enemy will not shy away from letting weapons speak, where and when he detects the slightest chance of carrying out his plans of aggression. Nobody can get around that. We therefore have every reason not to let up a single minute in our political and military vigilance. Our image of the enemy is accurate. There is nothing to be changed in that image because the enemy himself has not changed."[6]

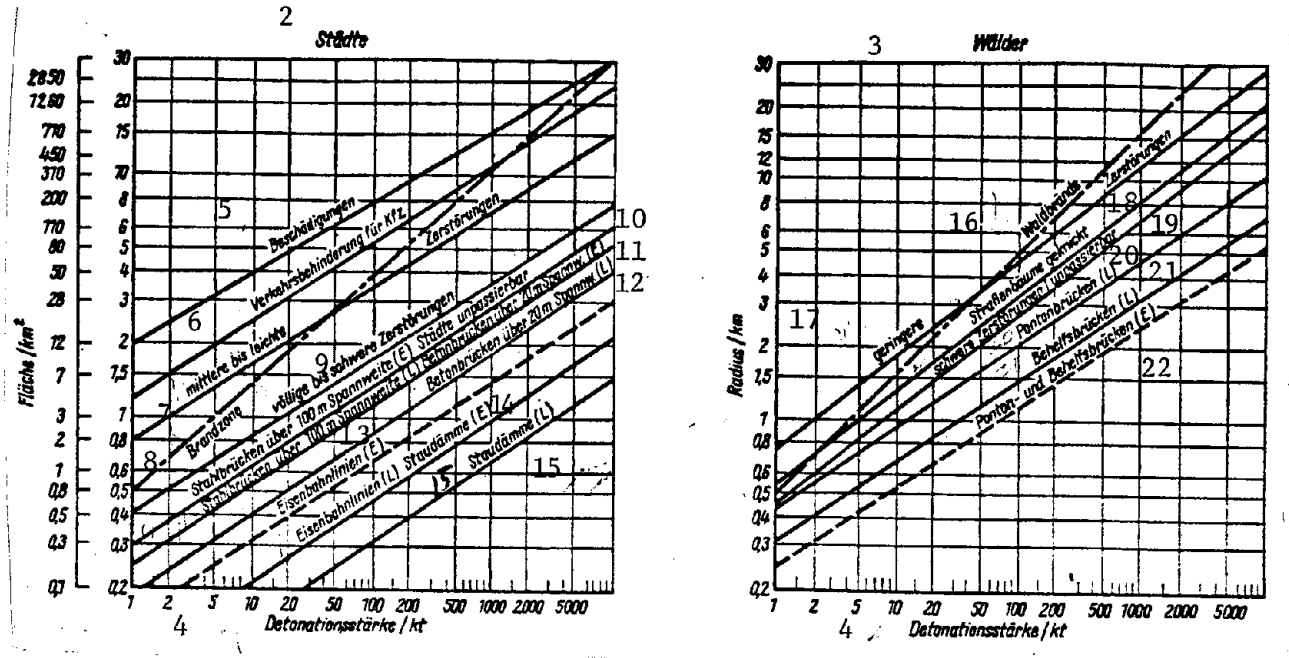


Figure 8.3. Radii of destruction zones in woods and cities as well as various traffic installations (reference values). Key: 1--Surface area, km^2; 2--Cities; 3--Woods; 4--Detonation intensity, kt; 5--Damage; 6--Traffic obstructions for motor vehicles; 7--Medium to light destruction; 8--Fire zone; 9--Complete to heavy destruction; 10--Steel bridges with more than 100 m span (E), cities, impassable; 11--Steel bridges with more than 100 m span (L), concrete bridges with more than 20 m span (E); 12--Concrete bridges with more than 20 m span (L); 13--Railroad lines (E); 14--Railroad lines (L), Dams (E); 15--Dams (L); 16--Forest fires; 17--Minor destruction; 18--Trees lining roads broken; 19--Heavy destruction, impassable; 20--Pontoon bridge (L); 21--Emergency bridge (L); 22--Pontoon and emergency bridges (E).

Review Questions

8.7. What measures are included in the elimination of the consequences of enemy nuclear strikes?

8.8. What special aspects apply to the elimination of the consequences of nuclear strikes under the conditions of severe terrain contamination?

8.9. What are the tasks of the rescue and recovery detachments? Derive their practical makeup in terms of manpower and equipment from that.

8.3. Footnotes for Chapter 8

1. See also Christians, H., "Comments on General Measures for Protecting Units Against Mass Annihilation Weapons," MILITAERWESEN, 1961, 1, pp 175-184; Nadirov, Yu. S., and others, "Zashchita podrazdeleniy ot oruzhiya massovogo porazheniya," Publishing House of the USSR Defense Ministry, Moscow, 1968, p12 p.

2. On this problem complex, see among others, Gillert, H., "On the Panic Problem in Modern Combat," MILITAERWESEN, 1962, 1, pp 51-62; Konieczny, St., "Panic in War," MILITAERWESEN, 1968, 6 pp 843-854.

3. In keeping with the selected organization of this textbook, there is no intention here to cover this problem complex systematically and completely in terms of content. Instead, we want to express some summarizing thoughts. In studying this chapter, one must therefore especially stress the tie-in with the subject matter presented in Sections 2.3, 3.5, 4.3, 5.3, 6.3, and 7.4.

4. DV-36/1, pp 45 ff.

5. The term "area hit" in this formulation does not do justice to the existing situation because this does not exclusively involve the question of nuclear radiation reconnaissance but rather concerns comprehensive reconnaissance of the overall situation arising after enemy nuclear strikes. Nevertheless, it was retained for the sake of uniform terminology.

6. Quoted from the Republic edition of NEUES DEUTSCHLAND [New Germany], 7 January 1972, p e.

List of Formula Systems Used

Generally valid, known symbols were not included in this list. The same applies to those symbols which were used only in a very special context and which therefore are not understandable by themselves alone.

A	Radioactivity Horizontal shift of earth's surface Mass number	A_f	Area [surface] radioactivity

A_1	Neutron induced radioactivity
A_v	Volume radioactivity
B	Buildup factor
C	Speed of sound in air Specific radioactivity
c	Speed of light
c_γ	Heat storage capacity
D	Nuclear radiation dose (ion dose of gamma radiation) Speed of blast wave
D_1	Integral Nuclear radiation dose
D_n	Dose of Neutron radiation
D_W	Horizontal diameter of detonation cloud
D_γ	Gamma radiation dose
d	Thickness Diameter
d_A	Diameter of pileup zone
d_H	Diameter of cavity in underground detonations with complete internal effect
d_{opt}	Diameter of detonation crater in case of optimum crater volume
d_p	Diameter of plastic deformation zone
d_R	Diameter of fissure formation zone
d_s	Diameter of visible crater
d_V	Diameter of condensation zone from underground detonations with complete internal effect
d_W	Diameter of real crater
$d_{1/2}$	Half-life layer of gamma radiation attenuation
E	Energy
E_B	Binding energy
E_{Det}	Detonation energy (total energy)
E_{kin}	Kinetic energy
E_L	Total energy of light radiation
E_{max}	Maximum energy
E_{Sp}	Energy released per atom nucleus split
$E_{\vartheta n}$	Energy released during fusion of two atomic nuclei
E_W	Contamination energy
$\bar{E}$	Average energy
E_γ	Energy of gamma quantum
E_β	Energy of beta particle
e^{-K}	Permeability factor of light radiation in air
F	Surface area Force
F_{KL}	Surface of nuclear charge
f_s	Attenuation [protection] factor of combat vehicles and shelters against gamma radiation from residual nuclear radiation
H_D	Detonation altitude
$-H_D$	Detonation or placement depth
$H_{D_{equ}}$	Equivalent (reduced) detonation altitude
$H_{D_{opt}}$	Optimum detonation altitude
$-H_{min}$	Minimum necessary detonation depth or "line of least resistance" for nuclear weapon detonations with complete internal effect
H_{so}	Fallout-safe detonation altitude
$-H_{opt}$	Optimum detonation depth
$-H_r$	Reduced detonation or placement depth
H_{St}	Climbing height of detonation cloud (cloud center)
$H_{St\ (ED)}$	Climbing height of detonation cloud from ground burst
$H_{St\ (uID)}$	Climbing height of detonation cloud from underground burst

H_z	Astronomic clock time of nuclear weapon detonation
$\bar{H}$	Altitude of upper cloud boundary
$\underline{H}$	Altitude of lower cloud boundary
h	Fallout altitude of radioactive particle
	Planck's action quantum
	Altitude [height]
h_A	Height of crater pileup
h_{opt}	Depth of detonation crater with optimum crater volume
h_S	Depth of visible crater
h_W	Depth of real crater
I_{ges}	Light energy radiated from surface of fireball per second
I_γ	Intensity of gamma radiation
I_0	Intensity of light radiation
K	Attenuation coefficient of light radiation for air
K^+	Scatter coefficient of light radiation for air
K'	Absorption coefficient of light radiation for air
k	Boltzmann constant
	Neutron multiplication factor
	Proportionality factor
k_a	Absorption coefficient of light radiation
k_d	Penetration coefficient of light radiation
k_r	Reflection coefficient of light radiation
k_γ	Dose constant
l	Length
m	Mass [weight]
	Attenuation factor of absorber against neutron radiation
N	Neutron number
N_A	Avogadro constant
N_β	Beta particle flux
n^β	Number of fission cycles
	Attenuation factor of absorber against gamma radiation
P	Dose rate from gamma radiation
P_{max}	Maximum dose rate
$P_{1\ h}$	Dose rate 1 hour after nuclear detonation
$P_{1\ km}$	Dose rate at kilometer point 1
$\bar{P}$	Average dose rate
p	Pressure [blast]
Q	Charge mass with efficiency η
Q'	Charge mass with efficiency $\eta = 1$
q	Detonation intensity [power]
R	Radius of fireball
	Radius of contaminated surface area
R_{equ}	Equivalent radius of fireball
$R_{equ\ (max)}$	Maximum equivalent radius of fireball
R_1	Radius of fireball during first period of its development
R_α	Range of alpha radiation
$R_{\beta\ (max)}$	Maximum range of beta radiation
$\bar{R}$	Average radius of fireball (radius of fireball at time of second temperature maximum)
r	Radius
	Distance
r_0	Distance from ground zero
S	Visibility range
s	Path [distance]
	Distance [segment]

T	Thermodynamic (absolute) temperature
T_{biol}	Biological half-life
T_{eff}	Effective half-life
T_t	Transmission factor of light radiation
T_{min}	Temperature minimum at end of first period of fireball
T_{phy}	Synonym for physical half-life $T_{1/2}$
$T_{1/2}$	Physical half-life
t	Time Time duration
t_a	Start of radiation effect
t_{Ausf}	Time duration of fallout of radioactive particles from detonation cloud
t_b	End of radiation effect
T_L	Duration of light from fireball (radiation time of light radiation)
t_m	Average time between two nuclear fissions Measurement time
$t_{Niederschlag}$	Start of radioactive fallout
$t(T_{max})$	Time of second temperature maximum of fireball
t_1	Duration of first development period of fireball Reference time
t_2	Duration of second development period of fireball Reference time
U	Light pulse Speed of air in blast wave
U_W	Heat pulse
V	Volume
V_L	Charge volume
V_T	Volume of detonation crater
v	Speed [velocity]
v_M	March movement speed
v_o	Initial velocity
$\bar{v}$	Speed of average wind Average speed
W	Work Separation work for one electron
w	Average fallout velocity of radioactive particle from detonation cloud
Z	Proton number, nuclear charge number
z	Number of nuclear fissions
Δ(Delta)	Whole-value layer of absorption of beta particles of given energy
ΔE_1	Ionizing energy
Δt	Time difference Time between two measurements
Δp	Overpressure
Δp_d	Dynamic pressure (impact pressure)
Δp_f	Overpressure along blast wave front
Δp_r	Reflection overpressure (reflection pressure)
ε(Epsilon)	Contrast threshold value of light radiation
η (Eta)	Efficiency
λ(Lambda)	Wavelength Heat conductivity
μ (My)	Linear attenuation coefficient of gamma radiation
μ_{eff}	Effective attenuation coefficient
ν (Ny)	Frequency
ϱ (Rho)	density
σ (Sigma)	Stefan-Boltzmann constant (radiation constant) Action cross-section
τ (Tau)	Time duration
τ_+	Duration of overpressure phase of blast wave
τ_-	Duration of under pressure phase of blast wave
φ (Phi)	Angle of incidence of light radiation.

Bibliography of Subject Field

A. Literature on Overall Field

1. Anonymous, "The Effects of Nuclear Weapons," Prepared by the United States Department of Defense, Washington, 1962; Russian edition from Publishing House of USSR Defense Ministry, Moscow, 1965, 679 p; FRG edition from Carl-Heymann Publishing House, Cologne, Berlin, Bonn, 1964, 712 p.

2. Anonymous, "Nuclear Explosions and Their Effects," Delhi, 1956; Russian edition from Publishing House for International Literature, Moscow, 1958, 195 p.

3. Anonymous, "Sredstva i sposoby zashchity ot atomnogo oruzhiya" [Means and Possibilities of Protection against Atomic Weapons], USSR Defense Ministry Publishing House, Moscow, 1965, 126 p.

4. Team of authors under the direction of Sokolovskiy, V. D., "Militaer-strategie," German Military Publishing House, Berlin, 1965, translation of Russian edition from USSR Defense Ministry Publishing House, Moscow, 1962, 458 p.

5. Blackett, P. M. S., "Angst, Krieg und die Atombombe - Atomenergie in Politik und Strategie" [Fear, War, and the Atomic Bomb--Atomic Energy in Politics and Strategy], Steinberg Publishers, Zuerich, 1950, 288 p.

6. Brodie, B., "Strategy in the Missile Age," The Rand Corporation, Princeton University Press; Russian edition from USSR Defense Ministry Publishing House, Moscow, 1961, 432 p.

7. Yegorov, P. T., and others, "Grazhdanskaya oborona" [Civil Defense], "Izdatel'stvo Vysshaya Shkola," Moscow, 1966, 216 p.

8. Yegorov, P. T., "Reaktivnoye oruzhiye" [Reactive Weapons], USSR Defense Ministry Publishing House, 1960, 224 p.

9. Yemel'yanov, V. S., "Atom i mir" [Atom and Peace], Atomizdat Publishing House, Moscow, 1964, 275 p.

10. Frankenberg, E. von, "Massenvernichtungswaffen" [Mass Annihilation Weapons], National Defense Ministry Publishing House, Berlin, 1958, 375 p.

11. Gallois, P., "Strategie de l'age nucleaire" [Strategy for the Nuclear Age], Callmann-Levy, Paris, 1960; Russian edition from USSR Defense Ministry Publishing House, Moscow, 1962, 208 p.

12. Gallois, P., "Technique et strategie" [Technology and Strategy], REVUE MILITAIRE GENERALE, [General Military Review], Paris, 1969, 7, pp 143-160.

13. Glushko, A. P., and others, "Nuclear Weapons and Nuclear Weapon Protection," Publishing House of the Ministry of National Defense, Berlin, 1960, 354 p; translation of Russian edition from USSR Defense Ministry Publishing House, Moscow, 1958.

14. Gvozdev, M., and Yakovkin, V., "Atomnoye oruzhiye i protivoatomnaya zashchita" (Atomic Weapons and Atomic Protection), Izdatel'stvo DOSAAF, Moscow, 1958, 240 p.

15. Hahn, B., "Basic Knowledge in the Field of Atomic Warfare," TRUPPENPRAXIS, Darmstadt, 1960, 3, pp 269-272; 6, pp 437-441; 9, pp 698-703; 11, pp 857-862.

16. Horlemann, H.-G., "The Effects of Atomic Weapons on Man," WEHRAUSBILDUNG IN WORT UND BILD, [Defense Training in Words and Pictures], Bonn, 1971, 12, pp 565-570.

17. Inglis, D., "Eskalation der neuen Waffen - Friede oder Untergang?" [Escalation of New Weapons--Peace of Perdition?], K. Desch, Munich, Vienna, Basel, 1969.

18. Ivanov, A., and others, "Raketno-Yadernoye oruzhiye i yego porazhayushcheye deystviye" [Nuclear Rocket Weapons and their Annihilating Effect], Voyenizdat, Moscow, 1971, 224 p.

19. Jastak, Z., "Informator o skutkach dzialania broniyadrowej," National Defense Publishing House, Warsaw, 1971, 203 p.

20. Jordan, P., "Future Outlook for Atomic Weapon Development," Wehrtechnik, Darmstadt, 1971, 4, pp 146-151.

21. Kahn, H., "On Thermonuclear War," Princeton, New Jersey, Princeton University Press, 1961, 668 p.

22. Langhans, K., "Nuclear Weapons and Their Effects," publication series on air raid defense, No 2, Interior Ministry Publishing House, Berlin, 1960, 126 p.

23. Lapp, R., "Atome und Menschen" [Atoms and People], New York, 1956, 240 p (English).

24. Lapp, R., "Murder and Mass Murder--Strategy of Extermination," New York, 1964, 144 p, (English).

25. Manstein, B., "Atomare Gefahr und Bevoelkerungsschutz--Wahrheit und Legend" [Atomic Threat and Civil Defense--Truth and Fiction], J. Fikn Publishing House, Stuttgart, 1965, 76 p.

26. Marfeld, A. F. "Atomenergie in Krieg und Frieden--Kernreaktoren und nukleare Waffen" [Atomic Energy in War and Peace--Nuclear Reactors and Nuclear Weapons], Safari Publishing House, Berlin, no year given, 500 p.

27. Mikhaylov, V. A., and I. A. Naumenko, "Yadernaya fizika i yadernoye oruzhie" [Nuclear Physics and Nuclear Weapons], USSR Defense Ministry Publishing House, Moscow, 1966, 224 p.

28. Michalski, H., "Pierwsze 100 godzin wojny nuklearnej" (The First 100 House of a Nuclear War), National Defense Ministry Publishing House, Warsaw, 1967, 476 p.

29. Moskalov, V. D., and others, "Textbook on Air Raid Defense," Interior Ministry Publishing House, Berlin, 1959, 232 p; translation of Russian Edition from DOSAAF Publishing House, Moscow, 1956.

30. Nadirov, Yu. S., and other, "Zashchita podrazdeleniy ot oruzhiya massovogo porazheniya" (Protection of Units against Mass Annihilation Weapons), USSR Defense Ministry Publishing House, Moscow, 1968, 222 p.

31. Pauling, L., "Leben oder Tod im Atomzeitalter " [Life or Death in the Atomic Age], Sensen Publishing House, Vienna, 1960, 183 p.

32. Pioro, T., "Bron jadrowa. Geza-dzialanie-skutki (The Nuclear Weapon--History of its Origin, Effect, Results), "Omega" Publishing House, Warsaw, 1971, 188 p.

33. Ponikarov, N. D., "Chto neobkhodimo znat' o Yadernom oruzhii i zashchite ot nego" (What One Must Know about Nuclear Weapons and Protections against Them), Atomizdat, Moscow, 1965, 166 p.

34. Schrader, R., "Die Wirkungen von Kernexplosionen--Waffentechnische Anwendung nuklearer Energie" [Effect of Nuclear Explosions--Weapon Engineering Application of Nuclear Energy], Soldat und Technik Publishing House, Umschau Publishing House, Frankfurt/M, 1958, 117 p.

35. Schrader, R., "The Physics of Nuclear Explosions and the Effect of Nuclear Weapons," NATURWISS. RUNDSCHAU [Natural Science Review], 1958, 7, pp 268-272; 8, 299-310.

36. Singh, N., "Nuclear Weapons and International Law," Inlitizdat Publishing House, Moscow, 1962, 350 p, (Russian); translation of the London edition of the year 1959.

37. Stockton, L. "Atoms, Characteristics and Effects," MILITARY REVIEW, 1958, August, pp 21-43.

38. U Thant, "Posledstviya vozmozhnogo primeneniya yadernogo oruzhiya, a takzhe posledstviya priobreteniya i dal'neyshego razvitiya yadernogo oruzhiya dlya bezopasnosti i ekonomiki gosudarstv" (The Consequences of the Possible Use of Nuclear Weapons on the Security and Economy of the State), Mezhdunarodnye Otnosheniya Publishing House, Moscow, 1970, 108 p.

39. Tompkins, J. S., "The Weapons of the Third World War," Publishing House of the USSR Defense Ministry, Moscow, 1969, 268 p., translation of the New York Edition, no year given.

40. Jungk, R., "Brighter than a Thousand Suns," Gosatomizdat Publishing House, Moscow, 1960, 280 pp, Russian; American edition from 1958.

41. Tsivilyev, M. P., and others, "Inzhenernyye raboty v ochage yadernogo porazheniya" (Engineer Construction Activities in the Nuclear Weapon Effect Center), USSR National Defense Ministry Publishing House, Moscow, 1968, 156 pp.

B. Literature on Individual Chapters

Classification, History, and Structure of Nuclear Weapons

42. Anonymous, "The Might of the Atom," PRAVDA, 24 December 1966, translation in "Die Presse der Sowtjetunion" [The Press of the Soviet Union], B edition, 1967, 6, pp 5-6.

43. Anonymous, "A World of Nuclear Powers?" A Report on the International Conference on Nuclear Weapons, 23-26 June 1966, Toronto, Canada, Englewood Cliffs, N.J., Prentice Hall, 1966, 12 pp.

44. Adler, I., "Inside the Nucleus," Atomizdat, Moscow, 1968, 149 pp, translation from English.

45. Article collection, "Elementary Particles," Gosudarstvennoye izdatel'stvo fiziko-matematicheskoy literatury, Moscow, 1963, translation from English, 103 pp.

46. Anureyev, I., "Ob opredelenii sootnosheniya sil po yadernomu oruzhiyu" (On the Balance of Power in Nuclear Weapons), Voyennaya mysl', Moscow, 31, 1967, 6, pp 36-45.

47. Blackett, P. M. S., "Militaerische und politische Folgen der Atomenergie" [Military and Political Consequences of Atomic Energy], book publishing section, General German Publishing House, Berlin, 1949, 292 pp.

48. Batunov, V., "Modern Nuclear Charges," TEKHNIKA I VOORUZHENIYE, Moscow, 1961, 3.

49. Buehl, A., "Atomwaffen" [Atomic Weapons], Osang Publishing House, Bad Honnef, 1968, 311 pp.

50. Brueckl, B., "The Way to the First Atomic Bomb," MILITAERWESEN, Berlin, 9, 1965, 7, p 979, 8, p 1138, 9, p 1266.

51. Clark, R. W., "The Birth of the Atomic Bomb," Gosatomizdat, Moscow, 1962, 168 pp, translated from English.

52. Dubovskiy, A. V., and others, "Kriticheskiye parametry sistem s delyashchimisya veshchestvami i yadernaya bezopasnost'" (Critical Parameters of Systems of Fissile Substances and Danger of Nucleus Formation), Atomizdat, Moscow, 1966, 255 pp.

53. Gordeyev, I. V., and others, "Yaderno-fizicheskiye konstanty" (Nuclear Physics Constants), Gosatomizdat, Moscow, 1963, 507 pp.

54. Groves, L. R., "Now I Can Speak Out--The History of the First Atomic Bomb," Kiepenheuer and Witsch, Cologne, Berlin, 1965, 411 pp, translated from English.

55. Hahn, O., "On the History of Uranium Fission and the Consequences Deriving from this Development," NATURWISSENSCHAFTEN, Berlin, Goettingen, Heidelberg, 46, 1959, 5, pp 158-163.

56. Hajek, "The Possibilities of Nuclear Reactions by Means of Hollow Charges," WEHRTECHNISCHE MONATSHEFTE [Defense Engineering Monthly], Frankfurt/M, 57, 1960, 1, pp 8-21.

57. Halpern, I., "Deleniye yader" (Nuclear Fission), Gosudarstvennoye izdatel'stvo fizikomatematicheskoy literatury, Moscow, 1962, 154 pp, translated from English.

59. Irving, D., "Virusnyy fligel'" (The Virus House), Atomizdat, Moscow, 1968, 349 pp, translated from English.

60. Konupka, F., "The Neutron Bomb," VOJENSKA TECHNIKA, Prague, 1961, 7, pp 8-9; 1961, 8.

61. Klose, K., "Subcaliber Nuclear Weapons," MILITAERTECHNIK, Berlin 7, 1967, 7, pp 301 to 303.

62. Langhans, K., "Modern Nuclear Weapons," MILITAERWESEN, Berlin, 7, 1963, 1, pp 54-74.

63. Matyukhin, Ye., "The United States Air Force--Carrier of Atomic Death," SOVETSKAYA ROSSIYA, Moscow, 1968, 26 January, translation in "Die Presse der Sowjetunion," B edition, Berlin, 1968, 23, p 3.

64. Novozhilov, Yu. V., "Elementarnyye chastitsy" (Elementary Particles), Gosudarstvennoye izdatel'stvo fiziko-matematicheskoy literatury, Moscow, 1963, 204 pp.

65. Pergent, J., "The Development of Atomic Armament," WEHRTECHNISCHE MONATSHEFTE, Frankfurt/M, 57, 1960, 9, pp 389-390.

66. Prosvirov, I., "Razvitiye yadernogo oruzhiya SShA" (Development of Nuclear Weapons in the United States," VOYENNYY VESTNIK, Moscow, 46, 1967, 1, pp 118-120.

67. Rougeron, C., "La Bombe a neutrons" (The Neutron Bomb), FORCES AERIENNES FRANCAISES [French Air Force], Paris, 16, 1961, 174, October, pp 429-442.

68. Rouze, M., "Robert Oppengeymer i atomnaya bomba" (Robert Oppenheimer and the Atomic Bomb), Atomizdat, Moscow, 1965, 147 pp.

69. Strauss, K. L., "Kette der Entscheidungen" [Chain of Decisions], Droste Publishers, Duesseldorf, 1963, 428 pp.

External Phenomena of Nuclear Weapon Detonation

70. Anonymous, "What One Must Know about Air Bursts, BOYOVA PRIPRAVA, Prague, 1964, 1, pp 56-58.

71. Anonymous, "Ucinky jadernych min" (Effects of Nuclear Mines), BOJOVA PRIPRAVA, Prague, 1967, 7, pp 26-27.

72. Anonymous, "Underground Nuclear Detonations," Inlitizdat, Moscow, 1962, 248 pp (Russian).

73. Anonymous, "Operation Argus," Atomizdat, Moscow, 1960, 120 pp (Russian).

74. Boehme, F., "Determination of Initial Data of Nuclear Weapon Detonations by Means of Visual Observation," GEFECHTSAUSBILDUNG [Combat Training], Berlin, 1969, 4, pp 25-30, and 39.

75. Brueckl, B., and U. Henning, "On the Use of Nuclear Charges for Blasting and Demolition Purposes," MILITAERWESEN, Berlin, 9, 1965, 12, pp 1734-1748.

76. Franko, J., "The Activity of Observers in the Determination of Nuclear Detonations," BOJOVA PRIPRAVA, Prague, 1962, 2, pp35-39.

77. Hardt, H.-J., and A. Rudloff, "Determination, Location, and Energy Value Calculation of Nuclear Weapon Detonations," ZIVILSCHUTZ, Koblenz, 30, 1966, 6, pp 209-212.

78. Hinzpeter, M., "Nuclear Weapon Tests and Atmospheric Processes," NATURWISSENSCHAFTLICHE RUNDSCHAU, 13, 1960, 4, pp 126-130.

79. Johnson, G. W., and others, "Underground Nuclear Detonations," J. GEOPHY. RES., 64, 1959, October, pp 1457-1470.

80. Johnson, G. W., and C. E. Violet, "Phenomenology of Contained Nuclear Explosions (Description of Concealed Nuclear Weapon Detonation), MCRL, 5124, Rev 1, December 1958, 27, Ref., NSA, 13, 1959, 9, No 7334.

81. Kellog, W., "The Rise and Development of an Atomic Cloud," AFCRC-TR-53-5 (Del), February, 1953, decl. 29 09, 1959, 11 pp; Ref., NSA 14, 1960, 5, No 4161.

82. Klose, K., "The Effect of Nuclear Weapons from Maritime Detonations," MILITAERTECHNIK, Berlin, 6, 1966, 1, pp 14-16.

83. Kravchenko, N., "Determination of Coordinates and Parameters of Nuclear Weapon Detonation," VOYENNYY VESTNIK, Moscow, 1971, 3, pp 91-96.

84. Krasavin, I. V., "Determination of Nuclear Detonation Intensity," VESTNIK PROTIVOVOZDUSHNOY OBORONY, Moscow, 1968, 7, pp 45-46.

85. Langhans, K., "Kernwaffenradiometrie und Kernwaffendetonometrie" [Nuclear Weapon Radiometry and Nuclear Weapon Detonometry], German Military Publishing House, Berlin, 1970, 478 pp.

86. Latter, R., and others, "Detection of Nuclear Explosions," ANN. REV. NUCLEAR SCI, 11, 1961, pp 371-418.

87. Nifontov, B. I., and others,"Podzemnyye yadernyye vzryvy," Atomizdat, Moscow, 1965, 160 pp.

88. Neklyudov, V., "The Earthquake and Nuclear Detonations," VOYENNYY VESTNIK, Moscow, 47, 1967, 4, pp 121-122.

89. Orphan, R., and R. Gerd, "Nuclear Blasting," Ordnance, Washington, 53, 1969, 293, pp 490-493.

90. Pasechnik, I. P., "Identification of Underground Nuclear Detonations," VESTNIK AKADEMII NAUK SSSR, Moscow, 38, 1968, 11, pp 99-104.

91. Singer, S. F., "Nuclear Explosions in Space," Missiles and Rockets 5, 1969, 13, pp 33-36; 14, pp 36-38; 16, pp 21-24; 16, pp 28-30.

92. Skopec, F., "The Nuclear Mine Belt in the GDR," VOJENSKA TECHNIKA, Prague, 10, 1968, 5, pp 155-157.

93. Weickmann, "Cloud Formations Caused by Atomic Bomb Explosions," METEOROLOGISCHE RUNDSCHAU [Meteorological Review], 1956, 1/2, p 1.

Blast Wave from Nuclear Weapon Detonation

94. Abramtsev, B., "Under the Conditions of Nuclear Weapon Employment," VOYENNYY VESTNIK, Moscow, 47, 1967, 6, pp 42-47.

95. Anonymous, "The Effect of the Blast Wave from Nuclear Weapon Detonations," MILITAERTECHNIK, Berlin, 4, 1964, t, pp 164-166; 6, pp 204-206.

96. Anonymous, "UN Expert Report on the Possible Consequences of a Nuclear War," DOKUMENTATION DER ZEIT [Documentation of Our Time], Berlin, 19, 1967, 396, pp 21-32, and 20, 1968, 397, pp 25-31.

97. Bade, E. "Protecting Traffic Installations against the Force of the Blast Wave Front from Nuclear Weapon Detonations," MILITAERWESEN, Berlin 5, 1961, 6, pp 852-856.

98. Tsirlin, A., "On the Effect on Unit Combat Operations," VOYENNAYA MYSL', Moscow, 23, 1959, 12, pp 40-47.

99. Coufal, J., "Exploiting the Protective Properties of the Terrain," BOJOVA PRIPRAVA, Prague, 1962, 5, pp21-24

100. Chumakov, V., "Suction Is also Dangerous," VOYENNYYE ZNANIYA, Moscow, 44, 1968, 1, p 24.

101. Chaszeyka, M. A., and F. B. Porzel, "Study of Blasts Effect in Soil," NP--7068, 1 8 1958, 119 pp, Ref. NSA 13, 1959, 1, 2106 and NP--7069, 1 5 1958, 35 pp; Ref. NSA 13, 1959, 3, 2107.

102. Gauvin, H. P., "The Attenuation Effects of Fog or Rain on the Peak Blast Pressure from an A-Bomb, AFCRC-TR-53-5 (Del.), February, 1953, decl. 29 9, 6 pp; Ref. NSA, 14, 1960, 5, No 4151.

103. Ginsburg, Th., "Action Diagrams for the Air Pressure [Blast] Effect on Nuclear Explosions," ZIVILSCHUTZ, 29, 9165, 11, pp 462-470.

104. Giovannini, E., "Some Considerations on Atomic War in the Mountains," ALLG SCHWEIZ. MILITAERZEITSCHRIFT [General Swiss Military Journal], Frauenfeld, 125, 1959, 8, pp 567-572.

105. Hartmann, G., "Terrain and Combat Operations," MILITAERWESEN, Berlin, 6, 1962, 7, pp 1079-1091.

106. Hartmann, G., "Der Einfluss des Gelaendes auf die Organisation und die Fuehrung von Gefechtshandlungen" [Effect of the Terrain on the Organization and Conduct of Combat Operations], German Military Publishing House, Berlin, 1966, 115 pp.

107. Katurkin, E., "Effect of Nuclear Detonations on Tank and Infantry Mines," VOYENNO-INZHENERNYY-ZHURNAL, Moscow, 102, 1958, 12, pp 42-44.

108. Katurking, E., "The Use of the Propertie : Vast Forests for Atomic Protection," VOYENNO-INZHENERNYY-ZHURNAL, Moscow, 103, 1959, 1, pp 33-36.

109. Kennedy, G. C. and G. H. Higgens: "Temperatures and Pressures Associated with the Cavity by the Rainier Event," UCRL--5281, July, 1958, 9 pp; Ref. NSA 13, 1959, 4, No 2278.

110. Klose, K., "The Blast Wave as an Annihilation Factor from Nuclear Weapon Detonations and Its Effect on Installations," MILITAERTECHNIK, Berlin, 9, 1969, 4, pp 166-168.

111. Neklyudov, V., and V. Samsonov, "Protection against the Penetration of the Blast Wave," TEKHNIKA I VOORUZHENIYE, Moscow, 1969, 10, pp 46-47.

112. Oborin, N. A., "The Effect of the Nuclear Weapon," VOYENNO-MED. ZHURNAL, Moscow, 1965, 4, pp 80-84.

113. Ricklin, P., "Mechanical Damage due to the Blast Wave from Atomic Weapon Employment," SCHWEIZ. Z. MIL.-MED [Swiss Journal of Military Medicine], Basel, 44, 1967, 4, pp 326-328.

114. Savchenko, A., "The Effect of the Blast Wave in Winter," TEKHNIKA I VOORUZHENIYE, Moscow, 27, 1969, 1 , pp 12-13.

115. Schafelberger, W., "The Reverse Slope," ALLG. SCHWEIZ. MILITAERZEITSCHRIFT, Frauenfuel, 125, 1959, 3, pp 173-187.

116. Serukhov, I., "In the Area of the Nuclear Weapon Strike," VOYENNYY VESTNIK, Moscow, 46, 1966, 10, pp 38-40.

117. Steenbeck, M., "The Effects of Nuclear Attacks on Densely-Populated Areas," WISS. WELT [Scientific World], Berlin, 13, 1964, 1, pp 22-28.

118. Zakrzewski, J., "Miasto w wojnie jadrowej" (The City in Nuclear War), WYDAW. MIN. OBR. NAROD., Warsaw, 1966, 278 pp.

Light Radiation from Nuclear Weapon Detonation

119. Anonymous, "Light Radiation from Nuclear Detonation," TEKHNIKA I VOORUZHENIYE, Moscow, 1963, 7, pp 38-42.

120. Anonymous, "Thermal Effects of Thermonuclear Explosions at Great Altitudes," ALLG. SCHWEIZ. MILITAERZEITSCHRIFT, Frauenfeld, 130, 1964, 5, pp 291-295.

121. Davis, T. P., and others, "The Scattering of Thermal Radiation into Open Underground Shelters, CEX-58.2, May, 1959, 24 pp, Ref. NSA, 14, 1960, 2, No 1180.

122. Ebeling, D., "Protection against Blinding from Atomic Explosions," ZIVILVERTEIDIGUNG, Bad Honnef, 34, 1970, 5 pp 35-37.

123. Feller, M., "The Effect of Light Radiation from Nuclear Weapon Detonation on the Eye," ZSCHR. MIL.-MED., Berlin 6, 1965, 2, pp 79-89.

124. Gessner, "The Atomic Bomb, Its Effect on Towns and Conclusions Concerning Civil Defense," PROTAR, 1957, 1/2, p 3.

125. Crzmil, St., "The Annihilating Effect of Light Radiation," MYSL WOJSKOWA, Warsaw, 12, 1961, 4, pp 57-69.

126. Holder, J., "Burns in the Context of Atomic War," SCHWEIZ Z. MIL.-MED., Basel 44, 1967, 4, pp 322-325.

127. Klose, K., "The Effect of Light Radiation from Nuclear Weapon Detonations," MILITAERTECHNIK, Berlin, 4, 1964, 3, pp 84-86, pp 126-128.

128. Kozak, J., and J. Moravoc, "The Effects of Light Radiation on Man," TYL A ZASABOVANI, Prague, XIX, 1969, 7, pp 8-11.

129. Laughlin, K. P., "Ignition Effect of Nuclear Weapons," ZIVILER LUFTSCHUTZ [Civil Air Raid Defense], Koblenz, 1959, 12.

130. Mattern, M., "Fires and Rescue Measures after Nuclear Attack," ZIVILSCHUTZ, 32, 1968, 6, pp 183-190; 7/8, pp 214-219.

131. Rohrschneider, W., and M. Hinterthaner, "Eye Damage due to Atomic Bomb Explosions," MUENCHENER MEDIZINISCHE [Munich Medical Weekly], 102, 1960, 22, pp 1097-1101.

132. Schubert, "Danger of Fire from Atomic Bombs," ZIVILER LUFTSCHUTZ, Koblenz, 1955, 12, p 327; 1956, 1, p 8.

133. Serashov, S. G., "Blinding and Retina Burns from Nuclear Detonations," VOYENNO-MED. ZH., Moscow, 1964, 10, pp 23-26.

134. Scoville, Jr., H., "Thermal Radiation from Atomic Weapons," AFCRC-TR-53-5 Del.), February, 1953, decl. 29 9 1959, 8 pp, Ref. NSA, 14, 1960, 5, No 4153.

135 Stewardt, H. S., "Weather Effects on Thermal Radiation," AFCRC-TR-53-5 (Del.), February, 1953, decl. 29 9 1959, 8 pp, Ref. NSA, 14, 1960, 5, No 4154.

136. Zhavoronkov, V., and R. Kalinichenko, "Nuclear Weapon Detonation and Fires," TEKHNIKA I VOORUZHENIYE, Moscow, 26, 1968, 3, pp 8-9.

137. Wegner, J., "The Effects of Light-Heat Radiation, Deriving from Thermonuclear Explosions on Man," ZCHR. MIL.-MED., Berlin, 2, 1961, 2, pp 70-74.

Instantaneous Nuclear Radiation from Nuclear Weapon Detonation

138. Anonymous, "Penetrating Radiation from Nuclear Detonation," TEKHNIKA I VOORUZHENIYE, Moscow, 1963, 8, pp 30-36.

139. Anonymous, "The Effect of the Annihilation Factor in Nuclear Weapon Detonations on Radio Electronics," MILITAERTECHNIK, Berlin, 8, 1968, 4, pp 167-169.

140. Baumgaertner, F., "Tabelle zur Neutronenaktivierung" [Table for Neutron Activation], Thiemig Publishing House, Munich, 1967, 47 pp.

141. Becker, K., and D. Nachtigal, "On the Biological Effectiveness of Neutrons from Nuclear Weapon Detonations," ZIVILSCHUTZ, Koblenz, 28, 1964, 11, pp 376-380.

142. Khromov, B. M., "Combined Radiation Damage," Akademie Publishing House, Berlin, 1964, 317 pp, translated from Russian.

143. Chuprin, Yu., "In the Radiation Field," TEKHNIKA I VOORUZHENIYE, 1968, 12, pp 12-13.

144. Grigor'yev, A., and L. Nikolayev, "The Effect of Penetrating Radiation," TEKHNIKA I VOORUZHENIYE, 1968, 10, pp 20-21.

145. Geipel, "Biochemical Processes in the Organism due to the Effect of Ionizing Radiation," ZSCHR. MIL.-MED, Berlin, 1, 1960, 2, May, pp 29-34.

146. Grodzenskiy, D. E., "Radiobiologiya," (Radiobiology), Gosatomizdat, Moscow, 1963, 108 pp.

147. Haller, U., "The Biological Effect of Nuclear Radiation," MARINEWESEN [Naval Affairs], Rostock, 6, 1967, 3, pp 333-341.

148. Koenig, W., "Biologische Strahlenwirkung und Strahlenschutz" [Biological Radiation Effect and Radiation Protection], Tribuene Publishers, Berlin, 1970, 53 pp.

149. Langendorf, H., "On the Question of the Radiation Threat to Man," ATOMKERNENERGIE [Atomic Nuclear Energy], 6, 1961, 6, pp 260-264.

150. Langhans, K., "The Nuclear Radiation Components of Nuclear Weapons--Neutron Radiation from Nuclear Weapons," MILITAERTECHNIK, Berlin, 10, 1970, 4, pp 172-173.

151. Langhans, K., "The Effect of Nuclear Weapon-Nuclear Radiation on Military Equipment," MILITAERTECHNIK, Berlin, 1, 1961, 5, pp 26-141.

152. Labordus, N., "The Biological Effect of Ionizing Radiation," POLYTECH. TIJDSCHR UITG. A, 14, 26/8 1959, No 35-36, 822a-25a.

153. Leypunskiy, O. L., "Gamma Radiation from Atomic Detonations," Atomizdat, Moscow, 1959, Russian.

154. Mather, R. L., "Chance Observations of Fallout Cloud Transit Radiations at Operation Plumbbob," USNRDL-TR-344, 30 1 1969, 20 pp; Ref. NSA, 13, 1959, 20, No 18009.

155. Poltavets, I. M., and others, "Ostryye radiatsionnye porazheniya i ikh lecheniye" (Serious Radiation Sickness and Its Treatment), Gosmedizdat, Kiev, 1962, 154 pp.

156. Paschnik, M. V. "Neytronnaya fizika" [Neutron Physics], Izdatel'stvo "Naukova Dumka," Kiev, 1969, 305 pp.

157. Savchenko, A., "Protection against Penetrating Radiation," TEKHNIKA I VOORUZHENIYE, Moscow, 25, 1967, 1, pp 32-35.

158. Schreiber, P., "The Development of Radiation Damage," MILITAERTECHNIK, Berlin, 7, 1967, 3, pp 111-113.

159. Schwenke, W., "The Biological Effect of Ionizing Radiation," WISSENSCHAFTLICHE ZEITSCHRIFT DER PAEDAGOGISCHEN HOCHSCHULE [Scientific Journal of the College of Education], Potsdam, 10, 1967, 3, pp 343-350.

160. Sens, G., "The Biological Effect of Neutron Radiation," ZSCHR. MIL.-MED., Berlin, 8, 1967, 1, pp 27-30.

161. Solov'yev, Ye., and Yu. Berezin, "Recording Neutron Radiation," TEKHNIKA I VOORUZHENIYE, Moscow, 1970, 10, pp 8-9.

The Electromagnetic Pulse from Nuclear Weapon Detonation and the Change of Certain Properties of the Atmosphere after High-Altitude Detonations

162. Anonymous, "The Electromagnetic Pulse from Nuclear Weapons," TIDSSKRIFT FOR SOVASEN, Copenhagen, 140, 1969, May, pp 269, 271.

163. Becker, K., "The Electromagnetic Pulse (EMP) after Nuclear Weapon Explosions," ZIVILSCHUTZ, Koblenz, 31, 1967, 2, pp 52-55.

164. Flambard, A., "Nuclear Detonations and Communications Links," REVUE DE DEFENSE NATIONAL [National Defense Review], 1966, 2, p 329.

165. Jastak, Z., "The Electromagnetic Pulse--The Fifth Annihilation Factor from Nuclear Weapon Detonations," "Przeglad Wojsk Iadowych," Warsaw, 13, 1971, 7, pp 100-119.

166. Kienert, M., "What Are the Effects of Nuclear Weapon Detonations on Radio and Radar?" MILITAERTECHNIK, Berlin, 6, 1966, 11, pp 413-415.

167. Moravec, J., "Is the Electromagnetic Pulse of a Nuclear Weapon Strike Dangerous to Rear-Echelon Logistic Support Services?" TYL A ZASOBOVANI, Prague, 19, 1969, 5, pp 20-21.

168. Traeumer, F., and E. Starik, "On the Effect of Nuclear Weapon Detonations in the Atmosphere on the Propagation of Radio Waves," MILITAERWESEN, Berlin, 9, 1965, 1, pp 91-108; 2, pp 234-256.

Residual Nuclear Radiation from Nuclear Weapon Detonation

169. Collection of Articles (conference minutes), "Radioaktivnyye izotopy v atmosfere i ikh ispol'zovaniye v meteorologii" (Radioactive Isotopes in the Atmosphere and Their Use in Meteorology), Atomizdat, Moscow, 1965, 491 pp.

170. Anonymous, "Radioactive Fallout and Nuclear Weapons Tests," NATURE, London, 192, 4 November 1961, No 4801, pp 400-403.

171 Anonymous, "The Nature of Radioactive Fallout and Its Effects on Man," Washington, 1957, 2065 pp.

172. Andrews, H. L., "Radioactive Fallout from Bomb Clouds," SCIENCE, 122, 1955, 9 September, pp 453-456.

173. Chugasov, A. A., "Radiatsionnaya razvedka pri yadernom napadenii" (Nuclear Radiation Reconnaissance), Atomizdat, Moscow, 1964, 87 pp.

174. Dobrovol'skiy, M., and S. Vekhov, "Water Contamination and Decontamination," TEKHNIKA I VOORUZHENIYE, Moscow, 1964, 4, pp 47-50.

175. Fano, U., and others, "Transmission of Gamma Radiation," Gosatomizdat, Moscow, 1963, 283 pp, translated from English.

176. Fish, B. R., "Surface Contaminations," Pergamon Press, Oxford, London, and others, 1967, 415 pp.

177. Fuchs, S., "Mathematical-Physical Considerations on Terrain Contamination after Nuclear Weapon Explosions," MILITAERWESEN, Berlin 8, 1964, 11, pp 1599-1609.

178. Fuchs, S., "The Effect of Turbulent Diffusion on the Contamination of the Surface and the Air Space after Nuclear Weapon Explosions," MILITAERTECHNIK, Berlin, 5, 1965, 8, pp 295-296; 9, pp 335-336.

179. Fuchs, S., "The Effect of Raindrops on the Transport of Small Particles through the Atmosphere," MILITAERTECHNIK, Berlin, 5, 1965, 10, pp 372-374.

180. Gusev, N. G., "Guide for Radioactivity and Radiation Protection," VEB Technik Publishing House, Berlin, 1957, 137 pp, translated from Russian.

181. Inikhov, G. N., "Al'fa - beta - gamma i neytronnye izluchateli" (Alpha-Beta-Gamma and Neutron Emitters), Gosatomizdat, Moscow, 1963, 76 pp.

182. Izrael', Yu. A., and E. D. Stukin, "Gamma-izlucheniye radioaktivnykh vypadeniy" (Gamma Radiation from Radioactive Fallout), Atomizdat, Moscow, 1967. 222 pp.

183. Klement, Jr., A. W., A Review of Potential Radionuclides Produced in Weapons Detonations, Wash - 1023, 30 7 1959, 107 pp, Ref. NSA, 14, 1960, 2, No 1341.

184. Klement, Jr., A. W., "An Estimate of Neutron-Induced Radioactivity in Soil from Weapon Detonations," M-7081 (Del.), 15 5 1958, decl. 22 4 1959, 3 pp, NSA, 13, 1959, 12, No 11052.

185. Lavrenchik, V. N., "Global'noye vypadeniye produktov yadernykh vzryvov" (Global Fallout of Nuclear Weapon Detonation Products), Atomizdat, Moscow, 1965, 169 pp.

186. Mikulek, M., "Determination of the Duration of Stay in Contaminated Areas," BOJAVA PRIPRAVA, Prague, 1963, 6.

187. Novakovich, M., "Equipment for the Preparation of Contaminated Water," VOJNOTECHNIKI GLASNIK, Belgrade, 1964, 5.

188. Petrov, R. V., and others, "Zashchita ot radioaktivnykh osadkov" (Protection against Radioactive Fallout), Medgiz, Moscow, 1969, 187 pp.

189. Piatkowski, A., "Radioactive Dust," MON, Warsaw, 1962, 200 pp (Polish).

190. Rudloff, A., "On the Question of the Duration of Stay in Radiation Shelters after Nuclear Weapon Detonations," ZIVILSCHUTZ, Koblenz, 29, 1965, 1, pp 25-27.

191. Rudloff, A., "Determination of Dose Rate and Dose in Case of Super-Position of Fallout Fields from Several Detonations," ZIVILSCHUTZ, Koblenz, 29, 1965, 2, pp 60-64.

192. Sitzlack, G., "Einfuehrung in den Strahlenschutz" [Introduction to Radiation Protection], VEB Volk und Gesundheit Publishing House, Berlin, 1971, 192 pp.

193. Spencer, L. V., "Protection against Gamma Radiation from Radioactive Fallout," Atomizdat, Moscow, 1965, 147 pp, translated from English.

194. Timofeyev, B. N., and Yu. K. Nesytov, "Prognozirovaniye radioaktivnogo zarazheniya" (Predicting Terrain Contamination), USSR Defense Ministry Publishing House, 99 pp.

195. Zubkin, A. S., "Obezzarazhivaniye territorii, sooruzheniy i transporta, podvergshikhsya vozdeystviyu oruzhiya massovogo porazheniya" (Special Treatment of Terrain, Installations, and Transportation Means, Exposed to the Effect of Mass Annihilation Weapons), Atomizdat, Moscow, 1965, 134 pp.

Nuclear Weapon Protection as Integral Component of Unit Protection against Mass Annihilation Weapons

196. Areczuk, A., "Protecting Units against Mass Annihilation Weapons," PRZEGLAD WOJSK LADOWYCH, Warsaw, 13, 1971, 6, pp 5-11.

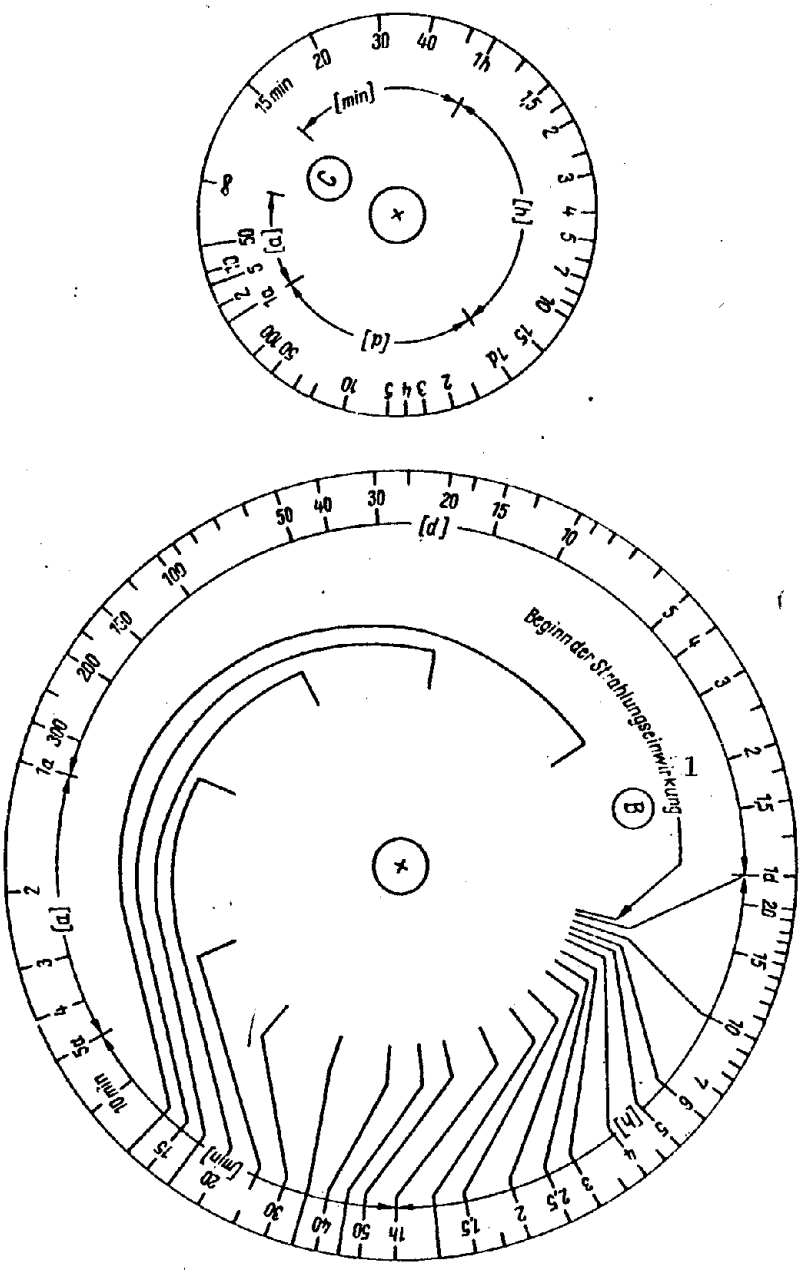
197. Dolodonov, S., "The Work of the Commander in Organizing Protection for the Battalion," VOYENNYY VESTNIK, Moscow, 1971, 5, pp 92-95.

198. Heinz, O., "Protection Training, Ideology, Class Struggle," GEFECHTSAUS-BILDUNG, Berlin, 1971, 12, pp 2-7.

199. Houser, M., "Operations by Units Hit by Nuclear Weapon Strikes," BOJOVA PRIPRAVA, Prague, 1971, 9, pp 18-21.

200. Lorber, K., "Protection against Mass Annihilation Weapons in the Woods," GEFECHTSAUSBILDUNG, Berlin, 1971, 9, pp 9-11.

0,1
0,2
0,3
0,5
1
2
3
5
10
20
30
50
100
200
300
500
1000
2000
3000
5000
10⁴
2·10⁴
3·10⁴
5·10⁴
10⁵
[R]
[R/h]
A
X



Key: 1--Start of radiation effect.